

# **WORLD SUSTAINABLE BUILDING 2014 BARCELONA CONFERENCE**



Sustainable Building: RESULTS

Are we moving as quickly as we should?

It's up to us!

**CONFERENCE PROCEEDINGS  
VOLUME 6**



This is the sixth of seven volumes of the Conference Proceedings for World SB14 Barcelona, which took place in Barcelona on the 28<sup>th</sup>, 29<sup>th</sup> and 30<sup>th</sup> October 2014.

The Conference was organised by GBCe (Green Building Council España), co-promoted by iiSBE, UNEP-SBCI, CIB and FIDIC, and counted on the participation of World GBC\*.

This volume gathers papers presented in the poster sessions from the Conference area “Creating New Resources”, presented at World SB14 Barcelona on day 2 of the Conference. All the papers in this volume were double blind peer reviewed by the [Scientific Committee of World SB14 Barcelona](#).

- If you wish you search for content by author or paper title, please use the [Conference programme search engine](#).
- If you wish to search for content by topic you can guide yourself by the topic labels that you will find at the top of the [Conference programme search engine](#).

All papers from World SB14 Barcelona have been granted the ISBN number 978-84-697-1815-5.

These Proceedings are published by GBCe, in Madrid, in November 2014.

Green Building Council España  
Paseo de la Castellana 114, 4º 7, puerta 7  
28046 Madrid

**\*iiSBE:** International Initiative for a Sustainable Built Environment

**UNEP-SBCI:** United Nations Environment Programme - Sustainable Buildings and Climate Initiative

**CIB:** Conseil International de Batiment

**FIDIC:** International Federation of Consulting Engineers

**World GBC:** World Green Building Council





## INDEX

### POSTER SESSION 3

<b>Energy Life Cycle Approach in two Mediterranean Buildings: Operation and Embodied Energy Assessment.</b>	1
<b>Window Thermal Performance Optimization in Governmental Emirati Housing Prototype in Abu Dhabi, UAE.</b>	9
<b>Lightweight Recoverable Foundations on Suitable Ground.</b>	16
<b>What to build after disaster? Sustainability assessment of twenty post-disaster shelters designs.</b>	23
<b>Spatial Analysis of LEED Certified Buildings in Canada.</b>	30
<b>Practical limitations in Embodied Energy and Carbon measurement, and how to address them: a UK case study.</b>	38
<b>A metaheuristic approach for heat pump scheduling.</b>	46
<b>The SYNERGY project: a holistic approach for assessing the energy, hygrothermal, fire and environmental performance of building elements.</b>	53
<b>Quality control mechanisms in building production management in Nigeria.</b>	61
<b>New Generation of Curtain Walls.</b>	69
<b>Hybrid Roofscape – Development and experimental results of roof-integrated PV/T-collectors for ZeroEmission-LowEx building systems.</b>	76
<b>For the last 20 years we have not heard in Russia about the sustainable development.</b>	83
<b>Innovating sustainable building design and built environment processes.</b>	86
<b>Technical knowledge transfer between Algeria and Italy: Oran, an experience of architectural rehabilitation.</b>	93
<b>The Challenge of limiting Energy Demand in Hot and Humid Regions and Mega Cities – Analyses with Integrated Building Sector Modelling.</b>	102
<b>Assessing the use of simplified and analytical methods for approaching thermal bridges with regard to their impact on the thermal performance of the building envelope.</b>	109



<b>Energy Saving Benefits of Daylighting Combined with Horizontal Exterior Overhangs in Hot-and-Humid Regions.</b>	116
<b>Study assessing the environmental performance of natural hydraulic lime.</b>	123
<b>The Effect of Material Service Life on the Life Cycle Embodied Energy of Multi-Unit Residential Buildings.</b>	129
<b>Sustainable Insulation Solutions: A lifecycle perspective from Cradle to Cradle. Tools for implementation.</b>	137
<b>Life Cycle Assessment within BNB1 – Online-Tool eLCA and materials database ÖKOBAU.DAT.</b>	144
<b>Sustainable urban housing. Strategies for implementation in Bogotá.</b>	152
<b>A Multi-scale Method to Optimize the Sustainability in Construction Works.</b>	159
<b>Service life of UK supermarkets: origins of assumptions and their impact on embodied carbon estimates.</b>	166
<b>A Comparative study of housing life-cycle carbon emissions for the characteristics of structural materials.</b>	173
<b>Development of a new type of HEMS (Home Environment and Energy Management System) for cohousing.</b>	180
<b>The non-use of sustainability performance tolos.</b>	187
<b>Carbon neutral living in a modernised settlement house.</b>	195
<b>Feasibility study of a hybrid ventilated classroom in hot-andhumid Climate.</b>	203
<b>Modulation performances in the building envelope: strategy and Project.</b>	210
<b>Assessment Factors of Sustainable and Healthy Environment for Hot Spring Hotels in Taiwan.</b>	222
<b>Integral Resilience – an indicator and compass for sustainability.</b>	229
<b>Residential areas retrofitting towards nearly Zero Energy Districts (nZED). A case study: Valladolid-Cuatro de Marzo.</b>	236



<b>The role of the urban support in the regeneration of vulnerable neighbourhoods.</b>	243
<b>A Project to Safeguard an Abandoned Heritage: The Revitalization of Golea (Algeria).</b>	250
<b>RESSÒ: energy efficiency urban rehabilitation.</b>	257
<b>Field Survey on Physical Activity Affected by Housing and Community.</b>	264
<b>Music for everyone: “building the space where the differences coexist”.</b>	271
<b>Embodied energy and embodied CO2 associated with buildings based on detail analysis and simple analysis.</b>	276
<b>Characterization of thermal insulation materials developed with crop wastes and natural binders.</b>	282
<b>UK experience of the use of timber as a low embodied carbón structural material.</b>	292
<b>Challenges of District Cooling System (DCS) Implementation in Hong Kong.</b>	299
<b>Analysis, valuation and opportunity of energy intervention in historic downtowns of European cities. The “Ensanche Cortazar” of San Sebastian.</b>	308
<b>Sustainable Improvement and Management for Deteriorated Urban Area In Developing Countries.</b>	315

## **POSTER SESSION 4**

<b>The methodology and case study of “Standards for Measuring, Accounting and Reporting of Carbon Emission from Buildings”.</b>	325
<b>Effects of façade on the energy performance of Education Building in Saudi Arabia.</b>	339
<b>Design and operation of a LEED platinum rated bottling plant in China – Swire Coca-Cola Luoche.</b>	347



<b>Rebuilding and a conscious and courageous leadership reduced energy consumption more than 80 percent.</b>	353
<b>The Preliminary model for the environmental oriental design of Kaohsiung Houses in Meinong.</b>	360
<b>A Post-Occupancy Evaluation Study of Traditional Shopping Street Reconstruction and Renovation — A Case Study of Sanfong Central Street in Kaohsiung, Taiwan.</b>	366
<b>Smart Interactive Buildings.</b>	373
<b>Architectural Implications in the Building Integration of Photovoltaic and Solar Thermal systems – Introduction of a taxonomy and evaluation methodology.</b>	380
<b>Grid Electricity Demand Reduction through Applying Active Strategies in Baghdad-Iraq.</b>	387
<b>The SUPER HABITAT Project.</b>	394
<b>Typology of Representative Dwelling Designs for Technical and Policy Purposes in Australia.</b>	403
<b>Modernization of Multi-Storey Apartment Houses.</b>	410
<b>Thermal Environment in Main Room Models of Contemporary Houses in Hokkaido, Japan.</b>	416
<b>A critical assessment of the housing sector in Algeria: beyond challenges and opportunities, a sustainable built environment at stake.</b>	423
<b>Life Cycle Analysis of standard and high-performance cements based on carbon nanotubes composites for construction applications.</b>	430
<b>A Building Products Procurement Platform for Environmental Evaluation of Design Alternatives.</b>	438
<b>Search for the environmental indicators relevant for the building Sector.</b>	445
<b>The Effect of a green roof on thermal comfort and learning performance in a naturally ventilated classroom in a hot and humid climate.</b>	456
<b>Using evolutionary optimization for low-impact solid constructions.</b>	463
<b>Responsible management of construction resources. Amortization of the concrete's embodied environmental impact as a sustainable strategy.</b>	470
<b>Rating Resource Efficiency of Building Materials.</b>	477



<b>“ 0-impact street”, for energy, materials, water and food.</b>	481
<b>Earthen Architectural Heritage (Rehabilitate the earthen construction in Saharan areas for sustainable development) Case of Wilaya of Adrar.</b>	488
<b>Examination and Assessment of the Environmental Characteristics of Vernacular Rural Settlements in Varying Topographies in Cyprus.</b>	494
<b>Análisis de la contribución de los aislantes a impactos provocados y evitados en Edificios.</b>	502
<b>Towards Creating New Sustainable Cities in Egypt- Critical Perspective for Planning New Cities.</b>	508
<b>Indicators of urban sustainability for a model of change.</b>	517
<b>A New Energy Model for Madrid: ‘Urban Nanoclimates’.</b>	524
<b>Methodology for Urban Comfort Management using Geo-Referenced Computer Applications.</b>	532
<b>Bio-climatic Design Handbook: designing public space to reach urban sustainability.</b>	539
<b>Emergent Trends in Architecture and Urbanism in Modern Cairo: Shifts in the Built Environment.</b>	546
<b>An approach to urban micro space sustainability. Sustainable assessment instrument.</b>	553
<b>The effect of land cover and land use on urban heat island in Taiwan.</b>	561

## **Energy Life Cycle Approach in two Mediterranean Buildings: Operation and Embodied Energy Assessment**

### **Speakers:**

Cellura, M<sup>1</sup>; Fontana, M<sup>2</sup>; Guarino, F<sup>3</sup>; Longo, S<sup>4</sup>; Mistretta, M<sup>5</sup>

<sup>1</sup> University of Palermo, Palermo, Italy

<sup>2</sup> University of Palermo, Palermo, Italy

<sup>3</sup> University of Palermo, Palermo, Italy

<sup>4</sup> University of Palermo, Palermo, Italy

<sup>5</sup> University of Reggio Calabria, Reggio Calabria, Italy

**Abstract:** *In the proposed work two case-studies were selected: the first one is a multifamily, high energy performance nearly Net ZEB located in central Italy; the second one is an existing standard Mediterranean single-family house in Sicily. The embodied energy and the operation energy were assessed for the case-studies, following a life-cycle approach, in compliance with ISO 14040 standards. In detail, when shifting from the standard building towards the high energy performance one, the relative share of operation energy decreases, while the embodied energy one increases. Therefore, the lower the operating energy, the more important it is to adopt a life cycle approach. The introduction of the life-cycle analysis introduces a further deficit in the energy balance from the neutral condition for the nearly Net ZEB case study. However, it emphasizes the embodied energy of the building as a key issues not to be neglected in the exhaustive evaluation of the energy demand of low energy buildings.*

**Keywords:** *Energy, Life-cycle approach, Net ZEB*

### **Introduction**

The reduction of energy requirement and the mitigation of environmental impacts in the building sector have become key targets of energy policies in different countries, to be matched by means of strategies aimed at the reduction of operation energy through the enhancement of energy efficiency and the spread of renewable energy technologies (Beccali et al., 2013). The Directive 2010/31/EC (the recast of EPBD 2002/91/EC) establishes the ‘nearly Zero Energy Building (ZEB)’ as the target within 2018 for all public owned buildings and within 2020 for all new buildings, pointing out that the energy required should be produced on-site or nearby renewable energy systems, thereby to reduce the consumption of primary energy and the related emission of greenhouse gases (Cellura et al., 2014). Buildings require energy over their life span; thus an exhaustive assessment of the environmental impacts may not neglect energy consumption, exploitation of natural resources and pollutant emissions in a life-cycle perspective. Until recently, only operating energy has been considered in many literature studies (Beccali et al., 2007), owing to its significant share in the total life-cycle energy consumption of standard buildings (70–90%). Conversely, embodied energy of building materials and components has been generally neglected in

building energy analyses, as in standard buildings it amounts up to 10–20% of the life cycle energy consumption. The definition of low-energy building strictly depends on climate, country, indoor climate and the user behaviour, which affects the energy consumption in each end-uses. Furthermore conversion factors from end-use to primary energy depend on the energy carriers used and the energy system of a specific country. Design of low energy buildings directly addresses the target of reducing the operating energy, by improving the thermal insulation of the building envelope, reducing infiltration losses, recovering heat from ventilation air and/or waste water, installing alternative energy using systems and renewable energy technologies for heating, domestic hot water and electricity generation. However, when shifting from standard houses to low energy buildings and to Net ZEBs the relative share of operating energy decreases, while the relative share of embodied energy increases. Therefore, the lower the operating energy, the more important it is to adopt a life cycle approach to compare the energy savings achieved in the building operation with respect to the overall life-cycle energy consumption (Blengini et al., 2010). Literature shows that low energy buildings have embodied energy in the range 10-100 kWh/(m<sup>2</sup>y), of which the highest values refer to the embodied energy of buildings sited in temperate and hot climate zones, while the lowest values refer to the embodied energy of cold climate buildings (Ramesh et al., 2010). The operating energy varies from nearly 0 to around 350 kWh/(m<sup>2</sup>y), moving from the NetZEBs to conventional houses in both climatic zones (Cellura et al., 2014). On the basis of the above considerations, in the following sections life-cycle approach is applied in order to assess embodied energy and operational energy in two building case-studies, in compliance with ISO 14044 standards (UNI EN ISO 14044, 2006): 1) the first one is a multifamily low energy building, which is located in central Italy; 2) the second one is a standard Mediterranean single-family house in Sicily. Tab.1 reports the main features for the two buildings under study.

*Tab.1. Building features*

Building features	Low energy building	Standard building
Number of levels	3	1
Heated floor area (m <sup>2</sup> )	610	110
Volume (m <sup>3</sup> )	1475	402
Heated floor to volume	0.33	0.27
S / V overall ratio	0.73	1.02

### Case study 1: the low energy building

Starting from the results of the SubTask B activities in the International Energy Agency (IEA) joint Solar Heating and Cooling (SHC) Task 40 and The Energy Conservation in Buildings (ECB) Annex 52 titled “Towards Net Zero Energy Solar Buildings”, the authors introduced apply the life-cycle perspective in the energy balance of a Net ZEB case-study (Cellura et al., 2011). Thus, not only the annual energy demand of Net ZEBs for operation energy, but also



the sum of all energies incurred in the other life cycle phases are assessed. For this purpose, embodied energy of the building and its components, including both initial and recurring one, and demolition energy for the building end-of-life are annualized and summed to the annual operating energy loads.

The building under study is an Italian multifamily house, the Leaf House (LH), located in central Italy, built according to the Italian requirements of the energy regulation in force, integrating different sources of renewable energy. The building is composed by three levels, each one containing a couple of twin flats. The heat generation is carried out by a geothermal heat pump (GHP), connected to 100 m long vertical probes, the solar thermal collectors and the auxiliary boiler. Each flat is heated by means of a radiant floor supplied by the GHP. The solar thermal system is installed to integrate the GHP in the DHW generation. The electricity requirement of the LH is supplied by a grid-connected PV system, with 20 kW peak power and 12% module nominal efficiency. To reduce the electricity consumption for lighting large windows face the south, while at the rear of the building facing the south solar tubes convey the sunlight indoor. Furthermore efficient fluorescent lamps are used. Water consumption is reduced by means of the collection of rainwater for sanitary and garden uses. A suitable building automation system optimizes energy performances of the LH, by stopping the HVAC system when windows are open, by regulating the inlet temperature of the water in the radiant floors according to the external temperature, and by regulating air flow rate according to the CO<sub>2</sub> level in each apartment.

## **LH life cycle energy analysis**

### ***Operation energy: monitoring of annual load and generation***

Operation energy is accounted starting from the outcomes of a one-year monitoring activity carried out in 2010. Electricity is required in the LH operation for space heating and cooling, ventilation, indoor lighting and plug loads, depending on the thermal performances and size of the building envelope, on the number of occupants and the activities inside. The flats account for around 34% of the total electricity consumption, while the thermal plant and, to a much smaller extent, the external lighting together account for the remaining 66%. With regard to the on-site energy generation, the PV system produces 24,664 kWh in 2010. Tab. 2 shows the outcomes of the annual LH final energy balance, assessed with regard to electricity. The annual energy balance is calculated. It shows a 0.9 MWh deficit. This outcome highlights that the LH can be considered a nearly Net ZEB, when the encountered energy flows are measured at the final level. However, when the annual energy balance is calculated in terms of primary energy, a shifting from the nearly Net ZEB condition, as final energy, to a non-Net ZEB condition, essentially due to the large difference between the conversion factors of PV electricity and imported electricity. The third column of Table 2 shows a significant increase of the deficit, in comparison with the first one. Such a deficit is about 57% of the imported primary energy not covered by the on-site generation according to the energy balance.



*Tab.2. Results of the energy balance*

<b>Electricity [MWh]</b>	<b>Final energy</b>	<b>Primary energy</b>
Imported from the grid	17.21	-40.76
Exported to the grid	16.3	17.44
Energy balance	-0.91	23.33

### ***Embodied energy and demolition energy***

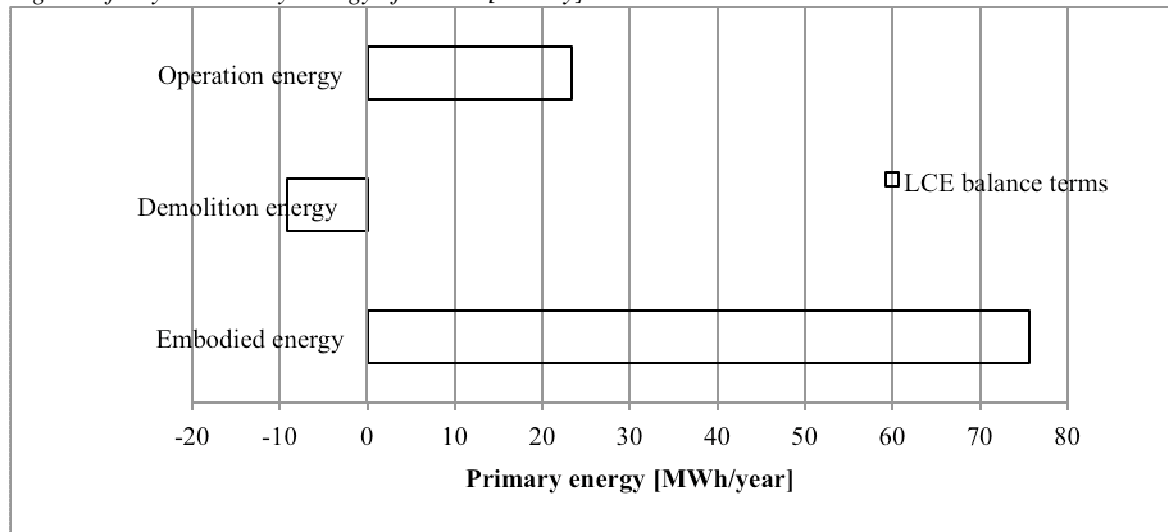
Embodied energy and demolition energy of the LH are assessed following a life-cycle approach, including the steps related to material and plant production, building erection and installation process, operation, maintenance/refurbishment and end-of-life. Embodied energy is estimated as the energy content, valued as primary energy, of the building related materials and components, and technical installations, including all the steps from the raw material acquisition to manufacturing processes. In such a definition, recurring embodied energy is also included, representing the primary energy consumption related to the maintenance and/or refurbishment of some building components and technical installations. In detail, energy consumption, owing to the transportation from the manufacturing gate to the construction site and to the erection step is also included in accounting for embodied energy. Furthermore, taking into account a lifespan of 70 years for the LH, and assuming one or more replacement for all the components with shorter lifespan, production and installation process of the replaced components are taken into account.

Demolition energy is estimated, including all the processes, which occur in the end-of-life of the building. Proper scenarios of dismantling and disposal/recycling of the C&D waste foreseen, depending on the distance from the LH to the site of disposal/recycling. All the energy consumption and environmental impacts due to transportation, demolition and recycling operations are calculated. The end-of-life of the replaced components in the refurbishment phase are also taken into account. The saved energy arisen from the avoided use of virgin raw materials, owing to the material recycling, is not assessed. The transportation of C&D wastes to recycling plants and/or disposal sites, when the end-of-waste state is reached, is also included. Data related to the existing building derive from Loccioni Group<sup>1</sup> and from some producers of building materials and plant components. Inventory datasets on energy supply (electricity and fuels) and transportation derive from (Öko-Institut, 2011). Life cycle inventory model is carried out by using the SimaPro software (PRè, 2010). Fuel consumption from transportation is calculated, depending on the transport mode and the distance between sites. With regards to the thermal plant equipment and the PV and solar thermal plants, the service life is estimated based on manufacturer's guarantees. Fig.1 shows the outcomes of the above described embodied energy (initial and recurring), demolition energy and operating energy, valued as primary energy and annualized taking into account the building lifespan. Globally, the annualized net primary energy consumption due to the whole life cycle of the LH is 89 MWh/y, of which the embodied energy and the demolition energy

<sup>1</sup> Loccioni Group, Angeli di Rosora, Ancona, Italy

result around 66 MWh/y, while operation energy results 32.6 MWh/y. With regard to the gross heated area (610 m<sup>2</sup>), the life-cycle net primary energy consumption is nearly 146 kWh/(m<sup>2</sup>y), of which 38 kWh/(m<sup>2</sup>y) is the operation energy and 108 kWh/(m<sup>2</sup>y) is the sum of the embodied energy and the demolition one. These results allow stating that compared with the literature case studies, the LH is representative of low energy buildings when life cycle perspective is taken into account.

Fig. 1. Life Cycle Primary Energy of the LH [MWh/y]



## Case study 2: Life-cycle energy in the standard single-family house

The standard building under study is a Mediterranean single-family house, located in Palermo in Southern Italy, 270 m above sea level, currently used by three occupants. It was built on one level with a heated area of 110 m<sup>2</sup>. The local climate has hot and wet summers, which affect significantly the energy demand for the building winter heating. The structural frame is made of reinforced concrete with masonry block walls. The external walls construction include 20 cm bricks with a 9 cm of cavity filled with foam vermiculite. The floor is 20 cm thick, including perforated bricks and prefabricated reinforced concrete rafters. The roof has a wooden structure with composite materials and clay roof tiles cover. The ground floor lays on a structure made of reinforced concrete and cave crushed stones. The external walls have a U-value of 0.96 W/m<sup>2</sup>K. The roof and the ground floor have a U-value of 0.60 W/m<sup>2</sup>K and 1.6 W/m<sup>2</sup>K, respectively. With regard to the transparent surfaces, the building is only equipped with wooden frame and double-glazing windows (U = 2.8 W/m<sup>2</sup>K). Heating and domestic hot water (DHW) are provided by a LPG (Liquefied Petroleum Gas) boiler. The heating system is equipped with steel radiators with insulated steel pipes for distribution. Summer air cooling is provided with reversible electrical heat pumps with an average seasonal energy efficient ratio of 3.3 in cooling mode. The life-cycle primary energy of the building is 25.9 MWh/y of which embodied energy represents the 26% (6.7 MWh/y) and demolition energy accounts only for 2% (0.56 MWh/y). The operation energy accounts for the highest contribution, that is about

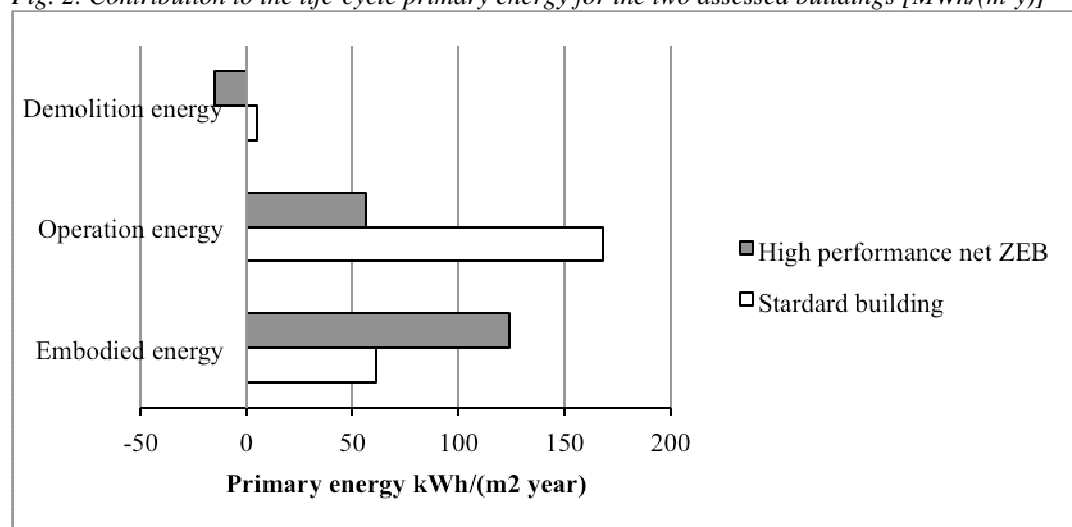
72% on life-cycle primary energy (around 18.6 MWh/y). Considering 50 years of lifespan for the building, the operation energy is estimated as the primary energy consumption for end-uses such as heating, cooling, domestic hotwater (DHW), lighting, electric devices, and cooking. A 3-year monitoring of the building end-uses is carried out to estimate electricity use for household appliances and cooling, LPG consumption for winter heating, DHW and cooking. The monitoring of the user behaviour during the operation step showed that the building annual operating energy mostly arises from the electricity consumption for lighting, electrical appliances and summer cooling, followed by the energy consumption for heating and DHW.

### Discussions and conclusions

Fig. 2 compares the life cycle energy results for the two assessed buildings, highlighting the contribution of each energy items to the total. In the standard house case study, the annualized life cycle primary energy consumption is 235.5 kWh/(m<sup>2</sup>y), with regard to the gross heated area (110 m<sup>2</sup>). The operation step involves the highest contribution to the life cycle primary energy consumption, accounting for 72% (about 169 kWh/(m<sup>2</sup>y)). It is mostly due to the electricity use for household appliances and summer cooling (108 kWh/(m<sup>2</sup>y)), while the remaining 61 kWh/(m<sup>2</sup>y) are due to energy consumption thermal uses. With regard to embodied energy, it accounts for 26% of the life-cycle primary energy consumption, that is 61.5 kWh/(m<sup>2</sup>y) while the demolition energy results 5 kWh/(m<sup>2</sup>y).

Unlike the standard house, in the low energy building case study the life-cycle energy consumption is dominated by the contribution of the embodied energy, which accounts for 75% while operation energy amounts to 34%. Demolition energy results -9 kWh/(m<sup>2</sup>y), thereby reducing the global life-cycle primary energy.

Fig. 2. Contribution to the life-cycle primary energy for the two assessed buildings [MWh/(m<sup>2</sup>y)]





The assessed case studies shows that there is a strict interplay among all the phases of a building life-cycle, as each one can affect one or more of the others, highlighting the relevance of the life-cycle approach to perform a reliable and complete building energy and environmental assessment. When shifting from standard building to low energy ones embodied energy increases, while the operation energy remarkably decreases. Obviously, the introduction of the life-cycle energy analysis increases the complexity of the energy balance calculation and introduces a further deficit in the energy balance from the neutral condition. However, it emphasizes the embodied energy of the building as a key issue to not be neglected in the exhaustive evaluation of the energy demand of low energy buildings.

## References

- Beccali, M., Cellura, M., Mistretta, M. (2007). Environmental effects of energy policy in Sicily: the role of renewable energy. *Renewable and Sustainable Energy Reviews* 11(2): 282–298, 10.1016/j.rser.2005.02.001
- Beccali, M., Cellura, M., Fontana, M., Longo, S., Mistretta, M. (2013). Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits. *Renewable and Sustainable Energy Reviews* 27: 283–293, doi:10.1016/j.rser.2013.05.040.
- Blengini, G.A. , Di Carlo, T. (2010). The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings. *Energy Buildings* 42: 869–880, 10.1016/j.enbuild.2009.12.009.
- Cellura, M., Campanella, L., Ciulla, G., Guarino, F., Nardi Cesarini, D., Lo Brano, V., Orioli, A. (2011). A net zero energy building in Italy: design studies to reach the net zero energy target, in: *Proceedings of 12th Conference of International Building Performance Simulation Association (IBPSA) Building Simulation*, Sydney, NSW, 14–16 November, 649–655.
- Cellura, M., Guarino F., Longo, S., Mistretta, M. (2014). Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study. *Energy and Buildings* 72:371–381, doi: 10.1016/j.enbuild.2013.12.046.
- Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).
- IEA SHCTask40/ECBCS Annex 52, Towards Net Zero Energy Solar Buildings, <http://task40.iea-shc.org/2013> (last accessed 25/05/2014).
- Öko-Institut & Gesamthochschule Kassel, GEMIS, <http://www.gemis.de>, Accessed September 12th, 2011.
- PRè-Product Ecology Consultants. SimaPro7.2, Environmental Database 2010. Amersfoort, The Netherlands.



Ramesh, T., Prakash, R., Shukla, K.K. (2010). Life cycle energy analysis of buildings: an overview. *Energy Buildings* 42 (10): 1592–1600, 10.1016/j.enbuild.2010.05.007.

Sartori, I, Hestnes, A.G. (2007). Energy use in the life cycle of conventional and low energy buildings: a review article. *Energy Buildings* 39: 249–257, doi: 10.1016/j.enbuild.2006.07.001.

UNI EN ISO 14040 (2006). Environmental management - Life cycle assessment- Principles and framework, International organisation for standardisation.

## Window Thermal Performance Optimization in Governmental Emirati Housing Prototype in Abu Dhabi, UAE

Abuimara, Tareq A<sup>1</sup>; Tabet Aoul, Kheira A.<sup>1</sup>

<sup>1</sup> Department of Architectural Engineering, United Arab Emirates University-Al Ain, UAE.

**Abstract:** *This paper focuses on the thermal optimization of windows in houses of the Emirati Housing program, launched by the government of Abu Dhabi, UAE. Typical units are implemented to suit planning objectives despite the impact of orientation on the building energy performance. Thus, the objective of this study is to explore window glazing specifications that provide optimum thermal performance for any building orientation. The dominant housing type in a representative Government Housing Program was identified along its construction components and windows' characteristics. The simulated energy performance of the existing design indicated variable annual energy consumption per orientation with the west carrying 9.7% more load than the east. Thereafter, thermally efficient glazing types were tested including; double reflective glass, double tinted Low-E and double squared Low-E. The double tinted squared Low-E glass yielded an overall measurable annual energy consumption reduction ranging from about 4 to 8% respectively for the east and west orientations.*

**Keywords:** *Window Design, Thermal Performance, Optimization, Housing, Hot Climate, UAE*

### Introduction

Presently, the United Arab Emirates (UAE) has one of the world's largest energy consumption per capita, with the building sector accounting for 70% of the consumed energy, primarily used for cooling. The building sector in the UAE has experienced a tremendous expansion due to population growth and economic development. Recently, the UAE government launched several housing programs intended for Emirati beneficiaries, while decisively targeting energy efficiency. The *Emirati Housing*, a representative housing program, aims at providing 13,000 detached houses by 2017. It targets the accommodation of cultural values and environmental adaptation while providing modern, sustainable homes that meet the local sustainability framework (Etidama) requirements.

Often enough, in these housing programs for architectural unity the housing units are implemented based on planning objectives with no specific accommodation of the different orientations, despite the impact of orientation on the building energy performance. Therefore, the objective of this study is to explore and identify window glazing specifications that provide optimum thermal performance for all building orientation.

### Housing and Energy Efficiency

Governmental housing was launched in the era that followed the discovery of oil. These housing projects were in the form of large numbers of detached houses with all related services and infrastructures. Houses were typical units with a limited number of typologies, sharing the same construction characteristics. Detached houses as skin loaded building type





[1], feature a large envelop that is exposed to solar radiation [2]. Under the extreme hot climate of the UAE, these detached houses are the most energy demanding type of buildings for cooling [2].

The nature of housing projects imposed typical designs with variable orientations in a way that meets planning objectives. However, each unit orientation may result in a variable thermal load and consequently excessive energy consumption for some. Windows are a critical building component and play an important role in determining the building energy efficiency. They can be a weak thermal link between the indoor and outdoor if they are not adequately specified [3]. Hence, designing a window that can mitigate the admission of heat under extreme hot regions such as the UAE is of great relevance. The optimization of the window thermal performance can be achieved through the improvement of several windows' aspects such as size, component material and shading of the window.

In governmental housing projects, where planning and allocation of houses are set according to planning objectives, the range of window thermal optimization lays mainly in the area of window's components; namely glass and frame. There has been a rapid improvement in construction material since the environmental issues; advanced types of framing and glass in terms of thermal efficiency, light and sound control have been introduced. For glass; tinted and coated glass, insulated glass, and smart glass types were introduced as thermally efficient glazing materials. Vinyl frames, wooden frames, clad frames and thermal break frames were types of thermally efficient ones. Window material selection should provide the optimum elimination of all forms of heat transfer through the window [4]. This calls for a combination of glass treatments that satisfies the heat elimination requirement.

### **Case Study: Al Falah Community in Abu Dhabi**

Al Falah community is a project of the Emirati Housing Program which was launched in Abu Dhabi as part of the plan Abu Dhabi 2030. It is designed to provide community facilities along with alternative housing options for the Emirati citizens. It consists of five residential villages with approximately five thousand residential detached houses coming in nine different designs in terms of size and architectural style [5]. The diversity in design aims at providing multi choices for local families to meet different family sizes and personal needs. Villas are located in large plots of over 1000 m<sup>2</sup> (30m x 35m), and surrounded by 2.5m high boundary walls [6]. Houses at Al Falah have nine different designs varying in terms of size and architectural style. Villas come in 3-bedrooms, 4-bedrooms, and 5-bedrooms typology ranging respectively from 300m<sup>2</sup>, to 350 and slightly over 450m<sup>2</sup>. Figure 1 presents the various architectural styles that otherwise share the same layout.

The units are implemented based on planning objectives with no consideration of orientation implication (Figure 2). Surveying available design and construction materials used revealed that only general sustainability measures were implemented in *Al Falah houses*. It includes materials with low heat transmittance (low U values), the selection of efficient HVAC equipment and the selection of water efficient fixtures. Windows frames are made of powder

coated aluminum profiles while the selected glass is tinted low reflective double glass with 6mm thick glass panes and 12mm air gap [8].



Figure 1: Architectural styles of the 5 bedroom houses in Al Falah community. Source [7]



Figure 2: Aerial view of the first phase of Al Falah community. Source: [9]

### Experiemental Investigation

The five bedroom villa was selected for the window optimization study as it accounts for about 50% of the total number of villas (Figures 3 & 4). An evaluation of ratios of glazing for each style per façade was carried out. The modern style emerged as the one that has the highest window wall ratio (WWR). Table 1 presents the detailed characteristics of the house.

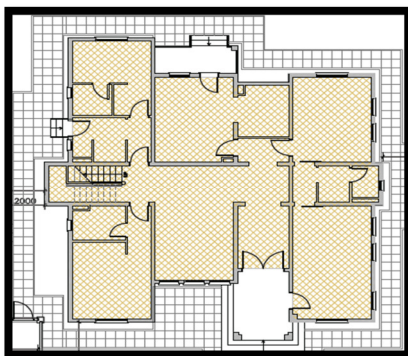


Figure 3: Typical ground floor plan for the five bedroom Villa



Figure 4: Base case model; Al Falah typical five bedroom villa (modern style)

### Thermal Performance of the Existing Design

The impact of orientation on the thermal performance of the existing design has been tested using Home Energy Efficient Design (HEED 4.0 build 34) software developed at the



University of California in Los Angeles. HEED is purposely dedicated energy evaluation tool for houses thermal performance and its output includes among other data the annual electrical energy consumption, cooling loads and lighting loads.

*Table 1: The Base Case; Specifications of Existing Building*

Category	Item	Description
Site	Location	Abu Dhabi 24.42 <sup>0</sup> N, 54.65 <sup>0</sup> E
Area	Total Area (GF+FF)	402.36 m <sup>2</sup> (4331 ft <sup>2</sup> )
	Floor Area (Footprint)	212.56 m <sup>2</sup> (2288 ft <sup>2</sup> )
	Overall Dimensions of the floor plan	17* 15.85 m (56 * 52 ft).
Envelop Construction Material	Windows	Double tinted low reflective glass with air gap
	Walls	Insulated concrete panels. (20cm thick concrete panel with 6cm polystyrene insulation) R=11; Calculated using Opaque (Version 2) software based on the existing construction detail. Wall/ ceiling: Reflectance 70%. Colors range between white and cream (construction documents: ALDAR,2009)
	Roof	Hollow core concrete slab with water proofing and heat insulation layers R=18; Calculated using Opaque (Version 2) software based on the existing construction detail.
	Reflectances	
Ratio of Glazing per Façade	Front Façade	26.55%
	Right Side Façade	13.4%
	Left Side Façade	9.03%
	Rear Façade	16.2%
Air Conditioning System	Package Unit	Seasonal Energy Efficiency Rate (SEER) = 13
Indoor Temperature	Lowest indoor comfort degree= 21.1 C (70F)	According to California Residential Code
	Highest indoor comfort degree= 23.88C (75F)	

The annual electrical energy consumption, cooling loads and lighting loads for each cardinal orientation of the existing design are presented in table 2 and figure 5. The base case testing has revealed a similar energy consumption rates when the model is oriented either to the north or to the south. The west facing model had the highest energy consumption rate. While, the east oriented model had the lowest consumption rate. The recorded difference between the highest and the lowest consumption rates is 8.85%. This reduction in annual electrical energy consumption refers to the reduction in cooling loads as it is reduced by 10.65% when rotating building form west to face east.

This reduction in cooling loads with the main façade orientated east can be easily explained because the east elevation receives the least amount of solar radiation. This radiation strikes the east during the morning hours, when temperature is still low. During the day, the east façade heat gain happens through heat transmission from the hot ambient air. The transmitted heat was mitigated because of insulated wall panels and insulated glass panels used for windows (double glazing). On the other hand, when the building is facing west, it starts to receive direct solar radiation during the afternoon until evening when the temperature is at its highest in addition to the transmitted heat from ambient hot air.

Table 2: The base case annual energy consumption, cooling loads and lighting loads per orientation

Power Usage (Kwh)	Orientation			
	North	South	East	West
<b>Total Annual Electrical Energy</b>	46,087.18	46,048.50	43,200.68	47,393.95
<b>Cooling Loads</b>	29,455.98	29,434.24	27,163.91	30,400.48
<b>Lighting Loads</b>	1,677.42	1,671.27	1,868.10	1,714.18

The first observation confirms the impact of orientation on heat gains and consequently on energy load, highlighting the impact of window design on the total energy used. The impact of orientation carried an additional 10% annual energy consumption from the west orientation compared to the east in this case. The higher ratio of glazing for the main façade is therefore directly affected by the change of orientation leading to higher heat gains.

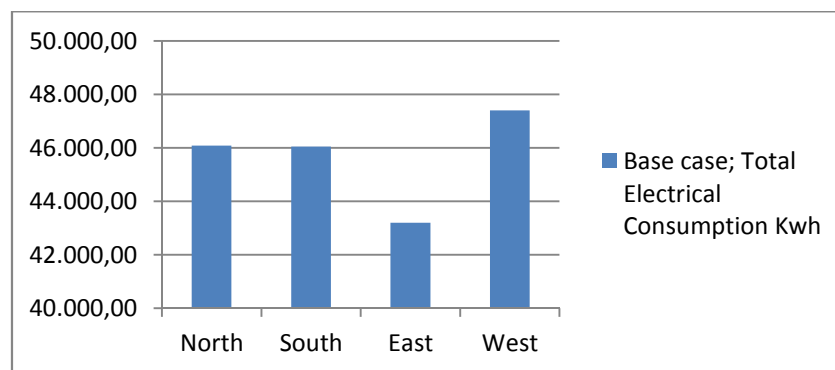


Figure 5: The base case annual energy consumption, cooling loads and lighting loads per orientation

### Glass Thermal Optimization

The glass optimisation investigation considered a number of energy efficient alternate options including: double reflective glass, double Low-E glass and double squared Low-E of which the thermal characteristics are listed in Table 3. The overall annual energy consumption, cooling and lighting load were evaluated for each type of glass in the four cardinal orientations.

The total annual electrical consumption indicates a differential result for the thermally efficient glass considered per orientation. The results reveals that the highest rate of savings

where obtained when using double tinted squared glass with all orientations (Table 4 & Figure 6).

Table 3: Thermally Improved Glass Alternatives

Glass Type	U Value	SHGC	Tvis
Tinted double pane glass (Existing Design)	0.81	0.45	0.57
Tinted double pane low E glass	0.69	0.39	0.53
Tinted double pane low E squared glass	0.67	0.25	0.38
Tinted double pane reflective glass	0.81	0.16	0.09

The savings ranged between 4% when facing east and about 8% for the west facing model. On the other hand the least savings were obtained when using double reflective glass with even an adverse impact in the east orientation where it generated about 1% increase when facing east in the total energy consumption due to the low visible transmittance of reflective glass that created significant increase in lighting loads.

Table 4: Annual Energy Consumption for the Thermally Improved Glass Alternatives.

Variable		North	South	East	West
Base case	Total (kwh)	46,087.18	46,048.50	43,200.68	47,393.95
Tinted, Double, Low E Glass	Total (kwh)	44,626.92	44,580.91	42,225.15	45,709.24
	Reduction %	3.17%	3.19%	2.26%	3.55%
Tinted, Double, Squared Low E Glass	Total (kwh)	43,072.78	43,045.74	41,846.74	43,663.94
	Reduction %	6.54%	6.52%	3.13%	7.87%
Double Reflective Glass.	Total (kwh)	44,665.09	44,616.05	43,573.18	44,869.22
	Reduction %	3.10%	3.11%	-0.86%	5.33%

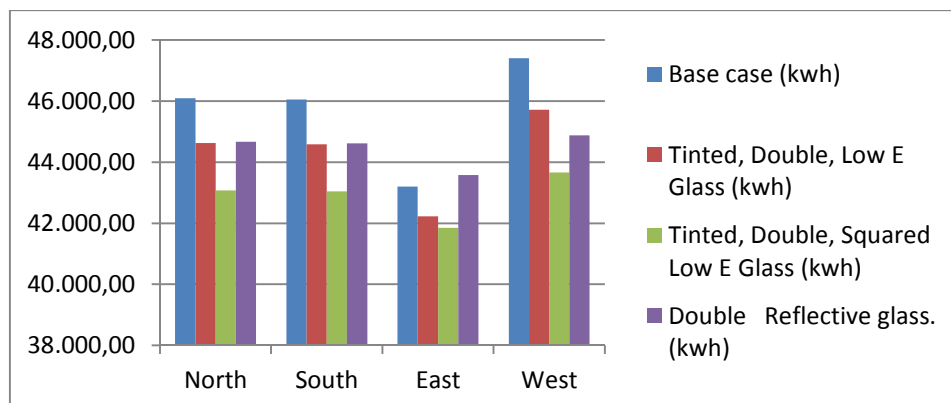


Figure 6: Annual Energy Consumption for Alternatives with Thermally Optimized Glass



The results in table 4 and figure 6 indicate an optimum thermal performance of windows with the highest savings. These savings were achieved because of the properties of double tinted squared Low-E glass combination. The multiple low emittances coating that minimize the radiative heat and the double panes that resist the transmitted heat.

Of more relevance to the objective of this study i.e. identify a glass that mitigates the impact of heat gain associated with orientation; it is interesting to note that the double tinted squared Low-E glass has achieved a similar thermal behaviour for all orientation (Table 4), which in turn enables planning flexibility along with measurable energy savings.

### Conclusion

This research has investigated the thermal optimization of windows glass in relation to orientation in a representative governmental housing project. This target enables flexibility in housing planning and at the same time offers energy savings.

The thermal performance of the dominant house type (five bedrooms with total built up area of 402 m<sup>2</sup>) has been initially tested in relation to the cardinal orientation. The west orientation consumed 9.7% more total annual energy than the east orientation. Subsequently, more efficient glass alternatives were identified, and tested including: double reflective glass, double Low-E glass and double squared Low-E. The Double Tinted Low E glass provided the optimum performance with saving ranging from 4 to 8% of the total annual energy consumption was achievable along with similar consumption rates for all orientations. Hence, some advanced types of glass can provide designers and planners with the required planning flexibility and the house owner with the additional energy savings.

### References

- [1] Lyons, P, (2001), The Energy Impact of Windows in Building Design, Environment Design Guide, Note PRO3, PEDP.
- [2] Clair, P., (2009), Low-Energy Design in the United Arab Emirates– Building Design Principles, PEDP.
- [3] Smith, P., (2005). Architecture in a Climate of Change. 2nd Ed. Architectural Press.
- [4] Cardomy, J, Haglund, K., (2012) “Measure Guideline: Energy-Efficient Window Performance and Selection” University of Minnesota, U.S. Department of Energy.
- [5] G.H.M, April. (2009), Detailed Planning Review Application, Villages\_2, 3, 4, 5, Part\_1.
- [6] G.H.M, Nov.(2008), Detailed Planning Review Application, Village one, Part\_1.
- [7] UPC (2011). Emirati Family Housing Program. Retrieved from: <http://www.upc.gov.ae/media/100294/upc%20emirati%20housing%20brochure%20final1.pdf>. [Accessed 20 May 2014].
- [8] ALDAR, (2009), Architectural Drawings Issued for Construction, Abu Dhabi: UAE.
- [9] RIAS. (2013). Al Falah New Town Masterplan, Abu Dhabi: RIAS. Retrieved from: <http://www.rias.org.uk/directory/practices/hypostyle-architects/al-falah-new-town-masterplan-abu-dhabi/>. [Accessed 20 May 2014]

## Lightweight Recoverable Foundations on Suitable Ground

**Abstract:** *One of the greatest challenges to be faced in the fight against climate change in the construction sector is the fact that (non-traditional) conventional solutions are routinely accepted despite their high environmental impact. In particular, reinforced or mass concrete foundations are used at almost all sites, but they require a large amount of material, involve high emissions (some toxic), are extremely heavy and cannot be recovered. It is surprising to observe that most recent constructions in which the environment is taken into account use such foundations.*

*This paper presents the results of the research carried out on **lightweight recoverable foundation solutions**. The aim is to dramatically reduce the amount of material and allow the foundations to be deconstructed and recycled along with the rest of the building, leaving the land clear for reuse.*

***Lightweight foundations, recoverable foundations, prefabricated foundations, site investigation.***

### Lightweight recoverable foundations

Lightweight recoverable foundations can be divided into two major groups: prefabricated and completed-in-situ foundations (cast-in-situ foundations are not considered because they pollute the subsoil and require large amounts of concrete).

LIGHTWEIGHT RECOVERABLE FOUNDATIONS ON SUITABLE GROUND	
<b>Prefabricated foundations</b>	Cylindrical and under reamed piles of wood, steel or concrete - Sheet piling – Strips and hollow or solid blocks - Supports, tripod, bases, piers, plates - Floating boxes or drums - Helical and screw piles - Grids
<b>Completed-in-situ foundations</b>	Semi-precast foundations and formworks - Micro piles - Composite piles

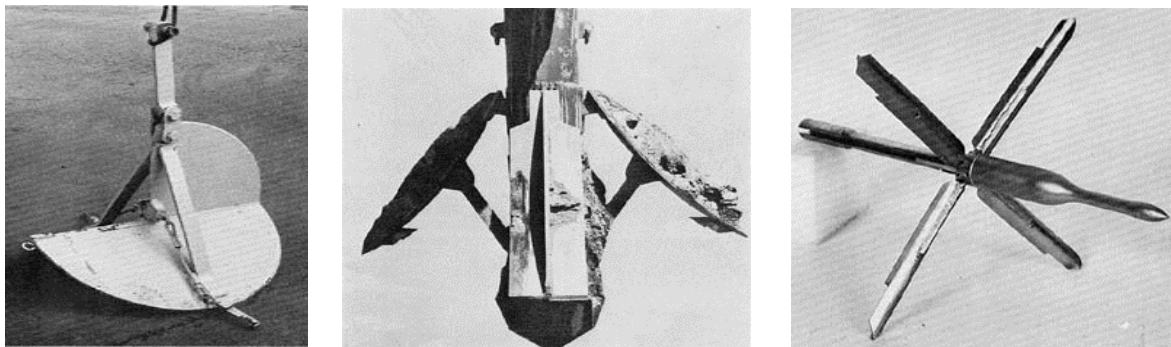
**Timber piling** (fig.1 to 3) is the lowest cost deep foundation material and lasts for over 100 years, with a natural taper that increases friction capacity. It can be easily delivered, handled and installed using existing driving equipment at close spacing, minimizing expensive floor slab thickness and resisting attack from acidic soils. It is also unaffected by stray electrical currents and no corrosion protection is required, taking advantage of a plentiful, natural renewable resource.

**Steel piles** (fig.4 to 6) are either pipe piles or beam sections like an H-pile. driven into the soil by repeated impulsive loads. They may be cylindrical or expandable. Expandable mechanisms significantly improve the efficiency by rising the ratio bearing capacity / self weight. Opening extensions is accomplished during the final phase of the driving.



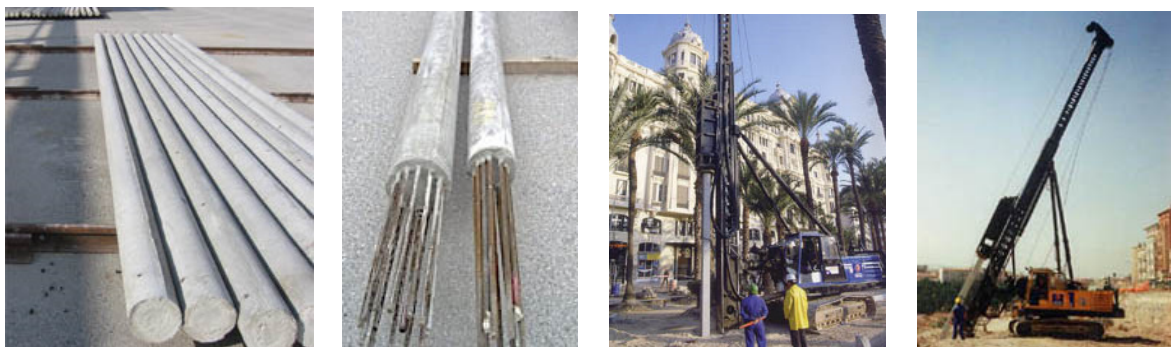


*Fig.1,2,3: Timber piling is the oldest foundation system, extensively used in many applications. It has recently emerged as a low-energy, cost-effective sustainable solution (fig.1,2,3 and: <http://www.geoforum.com/info/pileinfo/view.asp?ID=56>)*



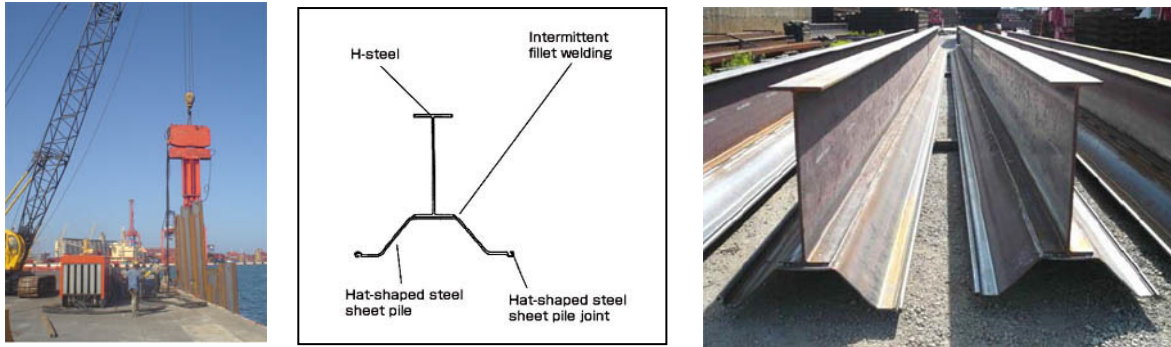
*Fig.4,5,6: Expandable steel piles: Y-shape, umbrella pile and Magnavox Company pile.*

**Precast concrete piles** (fig.7 to 9) are suitable for all applications and ground conditions and provide a very cost-effective solution. They are quick to install without producing spoil or arising material in the process, providing a further saving on waste disposal costs.



*Fig.7,8,9: Precast reinforced concrete piles may be driven vertical or inclined. Inclining the piles increase the horizontal bearing capacity.*

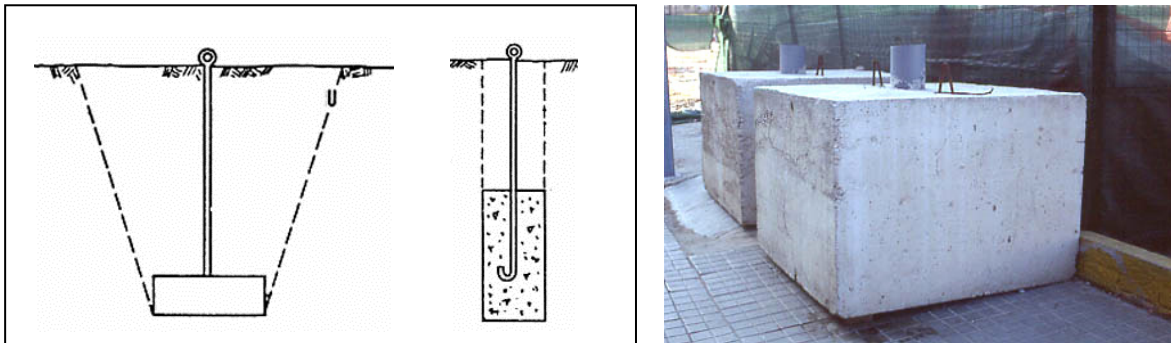
**Sheet piling** (fig.10 to 12) is a form of driven piling using thin interlocking sheets of steel to obtain a continuous barrier in the ground. The main application of sheet piles is in retaining walls and cofferdams but single or combined units may be employed as recoverable lightweight foundation. Vibrating hammers and cranes are used to install them.



*Fig.10,11,12: Installation of sheet-piles by vibro-hammering (left) and combined steel sheet pile.*



*Fig.13,14,15: Prefabricated strip footings, including tie beams, can be placed on the surface or buried.*



*Fig.16,17,18: Precast hollow or solid blocks and footings are usually buried. They may be placed on the surface in case of hard soils and bed rock to prevent or reduce excavation.*

**Supports, tripods, bases and plates** (fig.19 to 23) are ideal for light buildings supported by almost all kind of soils, provided they have some resistance. Single- family, semi-detached and row houses, mobile and manufactured homes, prefabricated 3D modules, emergency shelters, temporary dwellings and the like do not usually need large amounts of poured concrete, keeping in mind however that hazardous conditions such as strong winds and earthquakes may require complementary anchors to prevent overturning and uplift. Even if this was the case, note that anchoring to the soil is much more efficient than relying on weight.



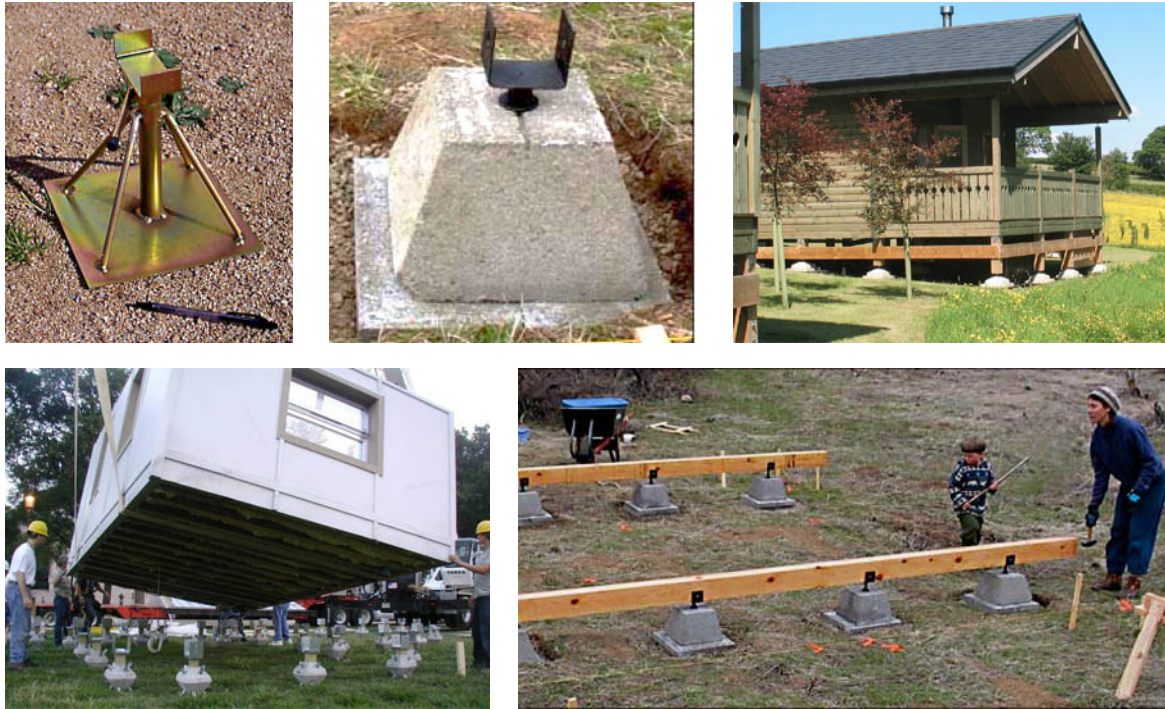


Fig.19,20,21,22,23: Light supports for light houses. Soft soils require compaction.

On soft and very soft soils it is also possible to avoid piling concrete by means of **floating boxes or drums**. It is the case of Holvast & Van Woerden: “De Fantasie” freestanding house in Almere (fig.24 to 25), a small residential core surrounded by scaffolding creating a spacious “outer house” which enwraps the living section like a well-fitting jacket.

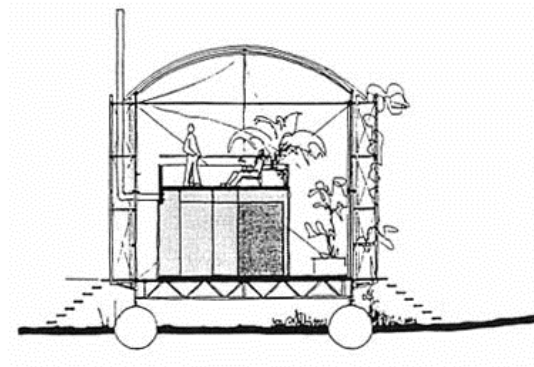


Fig.24,25: The foundations consist of hollow floats that could be used both on dry land and on water

**Screw piles** (fig.26 to 28) are slender shafts, having one or more single-turn helical surfaces, screwed into the soil. The diameter of the helixes, the number of the helixes, the magnitude of downward force applied during penetration, the depth of penetration, the applied torque and the strength of the shaft are varied to adjust to different soil conditions.





Fig.26,27,28: Screw piles are manufactured using varying sizes of tubular hollow sections. They are installed using earthmoving equipment fitted with rotary hydraulic attachments.

**Grillages** (fig.29 to 31) Steel grillage foundation consists of steel beams also known as grillage beams which are provided in single or double tiers. In case of double tier grillage foundation, the top tier is laid at right angles to the bottom one. On the other hand, where the soil encountered is soft and is permanently water-logged, building walls can be economically supported by suitably designed timber grillage foundation.

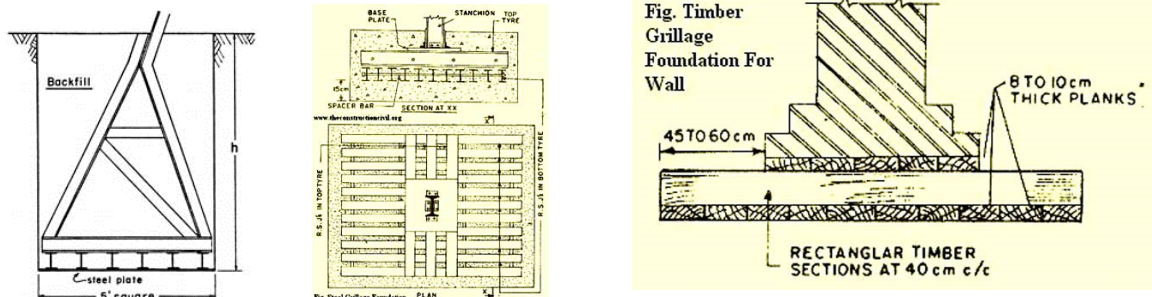


Fig.29,30,31: Grillages are frequently used in transmission tower foundations to avoid concrete.



Fig.32,33,34,35,36: Grouted bars and composite micropiles.

## Limitations

Lightweight recoverable foundations are not universally applicable. They are limited by urban planning, the type of building, the geotechnical survey and the contracting methods.

They can be used on all ground suitable for foundations of buildings ranging from one or two storeys (soft ground) to four and five storeys (hard ground) and therefore cover a large proportion of building needs. It is advisable to start by considering **the urban planning** and the geotechnical characteristics of the site in order to avoid the inappropriate solutions that are so common on the outskirts of large cities, as in the Llobregat and Besòs river deltas near Barcelona (figs 37, 38).



*Fig.37 San Cosme borough, Llobregat delta. Fig.38 La Mina borough, Besòs delta.*

Moreover, common practice of **subcontracting at the lowest price** benefits conventional-well known solutions obviating the overall costs in the short, medium and long term.

### **Geotechnical surveys and codes**

Geotechnical surveys should more accurately determine the mechanical characteristics of the ground to avoid underestimating the resistance of compact, hard and very hard ground because the current regulations allow far higher values than those that are now widely used.



*Fig.39,40 Unnecessary pollutant excavation in hard rock due to the application of criteria corresponding to soil.*



Rock mass requires characterization based on field investigation methods and techniques different from those used for soils. Compression strength and description of discontinuities are crucial. In the current Spanish code, the bearing capacity is evaluated from the unconfined compression strength, fracture spacing and joint aperture, not applicable to soil. However, most geotechnical surveys do not meet the code and apply tests and formulas corresponding to soils that results in over sizing the excavation, foundations, extra costs and delays (fig.39,40). In addition, conservative criteria applied to bracing in hard soils lead to useless tie beams (fig.41,42).



*Fig.41,42 Useless excavation and reinforced tie beams intended to brace the footings in hard rock.*

## Conclusions

Consideration of the environmental impact of foundations affects not only construction materials and solutions, which are usually already considered in the evaluation methods. It also affects urban planning, the choice of building type for the ground on which it rests, the geotechnical survey that provides the design values, and the contracting methods.

## Bibliography

B.M.Das (2004). "Principles of foundation engineering". Brooks/Cole-Thomson Learning, Pacific Grove.

Ministerio de la Vivienda (2006, 2007, 2008). "Documento básico SE-C. Seguridad estructural. Cimientos". Ministerio de Fomento, Madrid. Available at:

<http://www.fomento.gob.es/NR/rdonlyres/204AF31C-67E0-402A-BC8A-CB110C8E981F/95705/5.pdf>

Poulos, H.G. & Davis, E.H. (1980). "Pile foundations analysis and design". John Wiley & Sons, NY.

G.P.Tschebotarioff (1951). "Soil mechanics, foundations and earth structures. An introduction to the theory and practice of design and construction". McGraw-Hill, NY.



## **What to build after disaster? Sustainability assessment of twenty post-disaster shelters designs**

### **Speakers:**

Zea Escamilla, Edwin (EZE)<sup>1</sup>; Habert, Guillaume (GH)<sup>1</sup>; Lopez Muñoz, Luis (LML)<sup>2</sup>; Göswein, Verena (VG)<sup>1</sup>; Venzi, Micaela (MV)<sup>1</sup>

<sup>1</sup> Institute of Construction and Infrastructure Management, Chair of Sustainable Construction, Federal Institute of Technology (ETHZ), 8093 Zürich, Switzerland

<sup>2</sup> Research group on material analysis and design, National University of Colombia, Bogotá, Colombia

**Abstract:** *The number and intensity of natural disasters is growing every year, with 394 major events affecting over 268 million people worldwide in the past decade. Twenty transitional shelters were identified in 11 different locations worldwide. The objective was to identify which strategy for post-disaster reconstruction is the most appropriated between the uses of local or global materials. To compare the different transitional shelters, their environmental, economic, and mechanical/technical performances were assessed. For environmental and economic assessment life cycle cost and life cycle assessment were used. For the mechanical/technical assessment the relation between hazard zones and their performance was assessed for earthquake, wind loads and flood. Sustainability was assessed through a benchmark system that combined the results from those three categories. The results show that shelters with high technical performance can be achieved under low price/low environmental impact per functional unit whatever the type of material used.*

### ***Life cycle assessment, sustainable construction, transitional shelter, post-disaster***

#### **1. Introduction**

The number and intensity of natural disasters is growing every year, with 394 major events affecting over 268 million people worldwide in the past decade. Post-disaster shelters also known as transitional shelters[1, 2], had been defined by the International Federation of Red Cross and Red Crescent Societies, as a rapid living quarters made from materials that can be upgraded or re-used into more permanent structures[1, 2]. For over a decade, the need for a sustainability assessment of the built environment has driven the development of methods and tools[3] for the assessment of different types of buildings, residential, commercial and institutional. They make special emphasis on the environmental impacts related to the whole-life of buildings but a building can only be considered sustainable once the economic, social and cultural dimensions are taken into consideration[4]. Furthermore, these methods assess buildings against a set of predesigned criteria making them not so useful in the selection of optimal project options[5].

Twenty transitional shelters were identified in 11 different locations worldwide. Four main construction materials were identified: bamboo, concrete, steel, and wood. To compare the different transitional shelters, their environmental, economic, and technical performances were assessed. For environmental and economic assessment life cycle cost and life cycle assessment were used. For the technical assessment the relation between hazard zones in



which the shelters are located and their performance was assessed for earthquake, wind loads and flood.

The objective of the study was to identify which strategy for post disaster reconstruction is the most appropriated between the uses of local or global materials. Local materials require emphasis in structural design in order to produce structures that are able to withstand natural hazards, often rebounding on an increase of their economic and environmental cost. On the contrary, global materials can provide efficient structures that can resist natural hazards but with a much higher embedded energy than local materials.

## **2. Methodology**

For the sustainability assessment of the shelters three categories were defined. Environmental Impact, accounting for the effects on the natural environment from the production, and transportation of construction materials and shelters. Cost associated to purchase and transport of construction materials, and erection of shelters. And technical performance related to the risk zones in which the communities live and the mechanical performance of shelters in case of an event (earthquake, winds, and flooding). For each category a functional unit was defined. For environmental impact the shelter's covered area and life span were used as denominators. Project cost per shelter per covered area per life span. For the Technical category a ratio between risk/performance was developed.

### **2.1.Environmental Impact**

Life cycle assessment was used to evaluate the environmental impact of the proposed transitional shelters. This assessment method was developed to quantify the material use, energy use, and environmental impact associated with specific products, services, and technologies. LCA is described and standardised in ISO14040 [6] and consists of four steps: the definition of goal and scope, the development of life cycle inventories, impact assessment, and interpretation. LCA is an iterative process in which the goal and scope are constantly adjusted depending on the data collection limitations and the insights provided by the impact assessment[7]. The term "environmental impact" is used in LCA to refer to the effects of the studied system on the environment. These impacts depend directly on the evaluation method used during the impact assessment step. LCA has been applied in the construction sector for more than 20 years [8]. IMPACT 2002+ [9], which try to model the cause-effect chain up to the end point or damage point, sometimes with high uncertainty the damage-oriented IMPACT 2002+ v 2.1 method was used to reduce the number of impact categories. In this method, four categories are considered: human health, assessed in DALY; ecosystems quality, assessed in PDF.m<sup>2</sup>.yr; climate change, assessed in kg CO<sub>2</sub>; and resources, assessed in MJ. The results are normalised with the factors 0.0071 DALY, 13,700 PDF.m<sup>2</sup>.yr, 9,950 kg CO<sub>2</sub>, and 152,000 MJ for the respective impact categories. These factors represent the yearly emissions of one European citizen. This normalisation allows the results to be expressed in "points", with one point equal to the yearly emission of one European citizen in one impact category. As a final step, the results for the four impact categories were summed, considering an equal contribution for each category, and presented as a single score value[10].

The material amounts and locations of the shelters were based on the reports, 8 Shelter designs[1]; Post-disaster shelter: Ten designs[2]; Environmental impact of brick production outside Europe[11] and Optimization of bamboo based post disaster housing units for tropical and subtropical regions through the use of Life Cycle Assessment methodologies. These models represent the production phase of each shelter as well as transportation distances for the construction materials. Two types of distances were included: Local (Road) and International (Freight ship). All the LCA calculations were performed using the software SimaPro v 7.33 [12] and the database EcoInvent [13]. The life cycle inventories were summarized on a table that can be downloaded from the website: [http://www.ibi.ethz.ch/sc/people/assistance/zedwin/Sustainability\\_assessment\\_of\\_twenty\\_postdisaster\\_shelters\\_designs\\_LCIs.pdf](http://www.ibi.ethz.ch/sc/people/assistance/zedwin/Sustainability_assessment_of_twenty_postdisaster_shelters_designs_LCIs.pdf)

## 2.2. Cost

For the cost assessment the functional unit was the approximate project cost per shelter was/covered area m<sup>2</sup>/service life. Due to lack of a disaggregated cost of the shelter no further analysis could be done on this category.

## 2.3. Technical Performance

For this category a matrix was developed to quantify the performance of the shelters from the IFRC report [1] Transitional shelter-8 Designs and Post-disaster shelter: Ten designs[2]. The different types of hazards used to classify the risk of each location are described on **table 1**.

Table 1. Hazard risk classification

Hazard risk classification used in Section B for earthquake, wind and flood				
Classification used	Earthquake	Wind (approximate)		Flood
	Seismic Design Category *	Basic Wind Speed ** (km/hr)	Saffir/Simpson Hurricane Category	
LOW	B	<113	< 2	Low risk
MEDIUM	C	113-160	1 -- 2	Medium risk
HIGH	D	>160	3 -- 5	High risk

\* This is based on & ASCE/SEI 7-10, Table 11.6-1 assuming Risk Category I (Table 1.5-1 representing a low risk to human life in the event of failure) and based on the modified PGA.

\*\* The sustained 3 second gust speed at a height of 10m in flat open terrain for a 50 year return period (as defined in the & International Building Code (IBC) 2009, Section 1609. **Source:** IFRC [2])

The shelter's performance for each of the hazards are described in three levels. Green indicates that the structure meets the safety standards described on the international building code or local standards. Amber Indicates that the structural system does not fully meet the requirement of the International Building Code. However, the reduced design loads will not cause failure of individual members of the structural system. And finally Red Indicates that the reduced design loads will either cause complete failure of individual members or cause overall collapse of the structural system[2]. In order to assess the technical performance of the shelters, a matrix was developed where scores were defined for each hazard level and Performance of structures. The best score is obtained when the structure performs adequately (green) on the «high» level of hazard, as presented on **table 2**. The scores were calculated for earth quake, wind, and flood. An average of these scores was calculated for the final

Table 2. Technical performance assessment matrix

Hazard/ Performance	Green	Amber	Red
High	6	5	4
Medium	5	4	3
Low	4	3	2

Source: Authors



assessment.

### **3. Results**

This section presents the result for the three proposed impact categories Environmental impact, cost and technical performance. To assess the sustainability of these shelters and which strategy for post disaster reconstruction is the most appropriated, the results from the impact categories were combined on a benchmark system. In order to better represent the results the shelters were coded accordingly to the main construction material B for bamboo; C for concrete; S for Steel; and W for wood. The locations Afganistan, Bangladesh, Burkina Faso, Haiti, Indonesia, Pakistan, Peru, Philippines, Sri Lanka, Vietnam and Nicaragua were assigned the numbers 1 to 11 on this order. Two types of shelters were identified transitional and core shelters.

#### **3.1.Environmental Impact**

The results show that there is a wide variation on the impacts per functional unit on the shelters, but they are not dependant on the material used as can be seen in figure 1. On these figure it is possible to see that each of the construction materials can produce shelters with both low and high impacts per functional unit. The variation on the impacts is wider in the case of steel based shelters and narrow on bamboo based shelters. These results show that appropriated design and material selection play a an important role in the performance of these shelters.

#### **3.2.Cost Assessment**

The results from the cost assessment showed wide range of values. Six shelter designs achieved values under 1 CHF/m<sup>2</sup>/month. Further analysis on this category is not possible due to lack of disaggregated information regarding cost of materials, transport and construction. It is important to remark that these values depend highly on each case. Due to a number of unforeseen events and cost associated to the production of this kind of buildings, the variability and uncertainty of results is very high. Eventhough it is not possible to associate one construction technology / material to a certain price range, the results show that prices bellow 2.0 CHF/m<sup>2</sup>/month can be achieved.

#### **3.3. Technical assessment**

The results from the technical assessment showed that most of the shelters have a good performance in earthquake and flood events averaging 4.7/6.0 and 4.8/6.0 respectively. But most of the shelters have a relatively lower performance in the case of high winds where the average is 3.8/6.0. This is significant because while earthquakes and floods occur randomly, wind events occur periodically. Nevertheless, over 70% of the studied shelters have a technical performance above the mean score. These results show that the technical performance of the shelters cannot completely be correlated to its construction materials and/or techniques but it depends on the proper structural design for each risk zone.

#### **3.4. Sustainability assessment**

The studied shelters present very similar performances on the three categories, with exception of S4 Haiti. The results for this shelter were so extreme that it was necessary to remove it from



further calculation. The results show that shelters with high technical performance can be achieved under low price and low environmental impact per functional unit conditions as it can be seen in **figure 1**. It might be more cost effective to try to improve the technical performance from shelters like **B5**, **W1**, and **W6** than to reduce the cost and impacts from **S4**. Moreover, special attention shall be paid to the improvement of earthquake and wind resistance, which will increase the overall shelter's technical performance. Furthermore, a correlation between material and sustainability performance can be observed, but the limits of this relation need to be further discussed. These results indicate that both reconstruction strategies, using global materials like concrete and steel or local materials like bamboo and wood can provide sustainable reconstruction solutions, as soon as a proper design allow an efficient use of these materials.

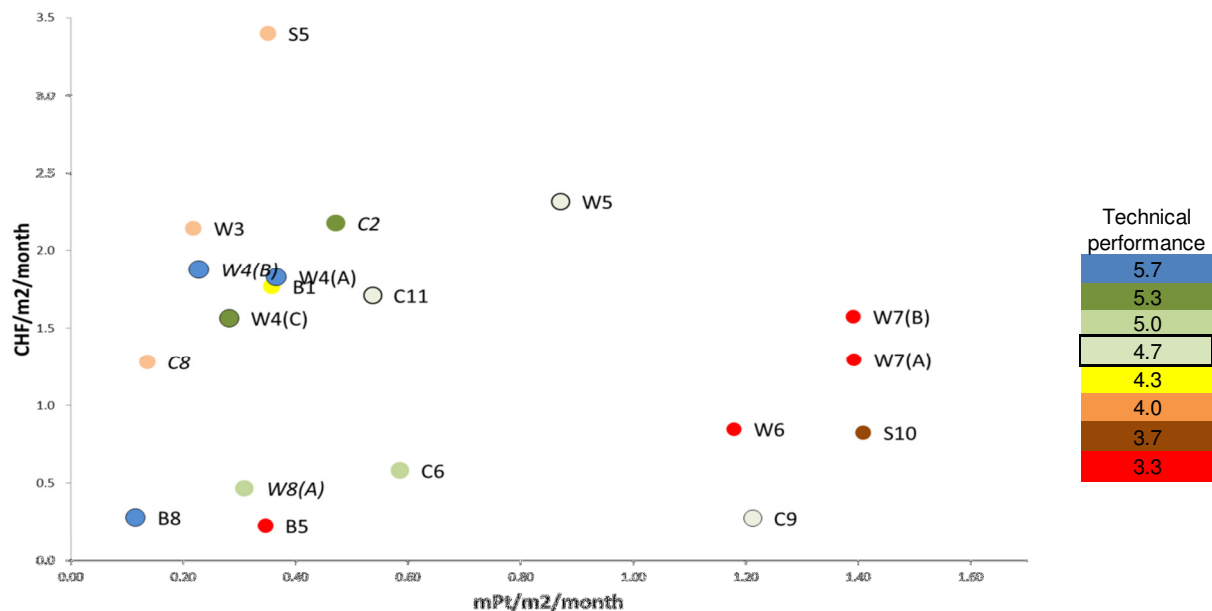


Figure 1 Sustainability assessment

#### 4. Discussion

The present research aimed to develop a methodology able to assess transitional shelters options, having in mind that main emphasis was made on selecting constructive systems that can produce disaster-resistant buildings under low cost/environmental impact conditions. To achieve this three impact categories were defined, in contrast to the work of Mateus et al [4] where three dimensions are split in nine categories and those on twenty five indicators. This approach however detailed is time demanding making it less suitable for this kind of projects. The proposed functional unit aims to address these complexities with the combination of three easy to measure factors for a single category/indicator. This approach proved to be useful not only in the assessment of Core and transitional shelter options but also to allow comparison between them.

Sensitivity analyses considering the variability of the results from the construction material perspective were used to validate the outcomes. In order to better understand how the results vary the shelters were clustered by the main construction material used. For each construction



material cluster the mean, lowest and highest values were calculated. This analysis was done for the three impact categories. For the technical performance category these analyses showed that all the construction materials are able to produce disaster resilient shelters. The concrete based shelters had the best performance on this category with the highest mean value and the narrowest variation of results of the construction materials.

The categories environmental impact and cost were further analyzed on a new benchmark using the values from the clusters as presented on **figure 2**. This figure shows that the bamboo based shelters can provide the lowest impact and cost pre functional unit. It also shows that the best concrete and wood shelters perform better than the worst bamboo shelters. This reaffirms the previous statement that appropriated design and material selection are key parameters for this kind of buildings. Moreover, This results are in line with the work of Wallbaum et al, [14] where bamboo, concrete and wood were identified as most promising technologies on the field of affordable housing. Similarly, the work from Cabeza et al[15], indicates that in terms of embed energy per square meter of build area these construction materials will the same ranking as the results shown on **figure 2**.

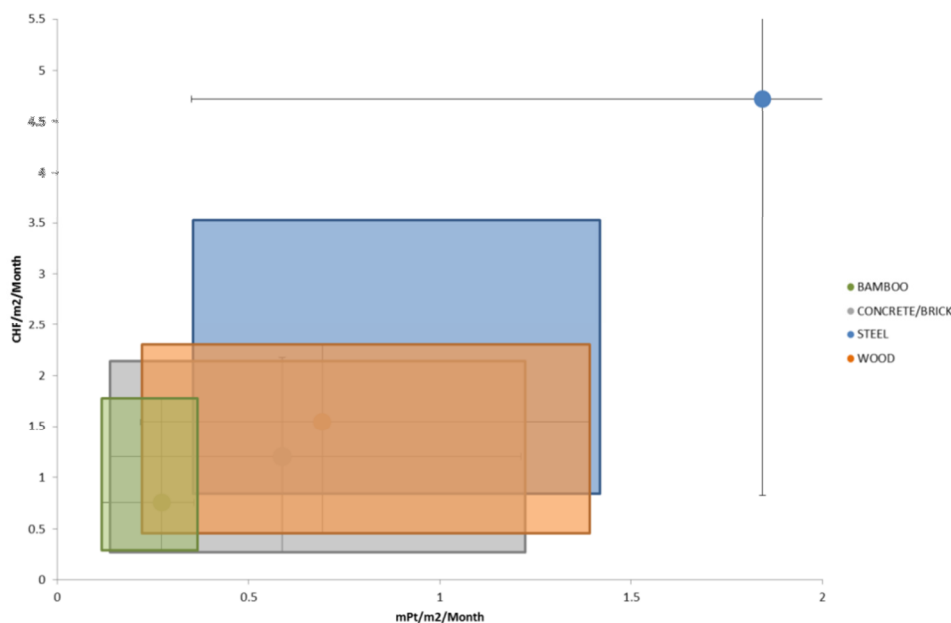


Figure 2 Variability Analysis

These studies[14, 15] show as well that no significant differences can be found the performance of the studied construction materials, reaffirming the idea that local or global materials can produce sustainable solutions having in mind that the potential to produce lower impacts and cost are higher when using bamboo based, concrete and wood.

## 5. Conclusions

From the sample studied shelters it can be concluded that the proposed functional unit was able to produce comparable results from diverse construction materials and shelters types. Furthermore, the method developed here allowed identifying the most appropriated material /



design combination able to withstand local natural hazards with the lowest economic and environmental cost. From these results it can be seen that shelters with high cost and/or environmental impacts do not necessarily perform the best from a technical point of view. The results showed that no direct correlation between construction material and shelter's sustainability was found but that appropriated design and material selection drive the sustainability of the studied shelters. It was also found that both global and local construction materials can be used to produce sustainable solutions for post disaster reconstruction projects, with local materials having higher potential for low environmental impacts and cost and global materials having better technical performances.

## 6. Acknowledgements

The authors will like to thank, the students that took part of the BSc Project in spring 2013. The International Federation of Red Cross and Red Crescent Societies for their support in and their constructive advice. **HILTI AG** for their long term support in the development of the present research project.

## 7. References

1. IFRC, (2011) *Transitional shelters – Eight designs*. International Federation of Red Cross and Red Crescent Societies. Geneva, Switzerland
2. IFRC, (2013) *Post-disaster shelter: Ten designs*. International Federation of Red Cross and Red Crescent Societies. Geneva, Switzerland
3. Haapio, A. and P. Viitaniemi, (2008) A critical review of building environmental assessment tools. *Environmental Impact Assessment Review*. 28(7): p. 469-482.
4. Mateus, R. and L. Bragança, (2011) Sustainability assessment and rating of buildings: Developing the methodology SBTool PT-H. *Building and Environment*. 46(10): p. 1962-1971.
5. Ding, G.K., (2008) Sustainable construction—the role of environmental assessment tools. *Journal of Environmental Management*. 86(3): p. 451-464.
6. ISO14040, (2007) *Environmental Management- Life Cycle Assessment- Principles and Framework*, ISO.
7. Bauman, H. and A. Tillman, (2004) *The Hitch Hiker's Guide to LCA*: Studentlitteratur AB.
8. Fava, J.A., (2006) Will the next 10 years be as productive in advancing life cycle approaches as the last 15 years? *International Journal of Life Cycle Assessment*. 11: p. 6-8.
9. Jolliet, O., et al., (2003) IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. *International Journal of Life Cycle Assessment*. 8(6): p. 324 - 330.
10. Zea Escamilla, E. and G. Habert, (2014) Environmental Impacts of Bamboo-based Construction Materials Representing Global Production Diversity. *Journal of Cleaner Production*.
11. Balzarini, A., Environmental impact of brick production outside Europe. (2013). Swiss Federal Institute of Technology ETH Zürich. Department of Civil, Environmental and Geomatic Engineering. Research.
12. Pre-Consultants. *SIMA Pro v7.3.3*. (2012); Available from: <http://www.pre-sustainability.com>.
13. SCLCI. *EcoInvent Database*. (2011); Available from: <http://www.ecoinvent.org>.
14. Wallbaum, H., et al., (2012) Indicator based sustainability assessment tool for affordable housing construction technologies. *Ecological Indicators*.
15. Cabeza, L.F., et al., (2013) Affordable construction towards sustainable buildings: review on embodied energy in building materials. *Current Opinion in Environmental Sustainability*. 5(2): p. 229-236.

## Spatial Analysis of LEED Certified Buildings in Canada

Hossaini, Navid NH<sup>1</sup>; Hewage, Kasun KH<sup>2</sup>; Sadiq, Rehan RS<sup>3</sup>

<sup>1</sup> School of Engineering, University of British Columbia, Kelowna, Canada

<sup>2</sup> School of Engineering, University of British Columbia, Kelowna, Canada

<sup>3</sup> School of Engineering, University of British Columbia, Kelowna, Canada

**Abstract:** *The Building and Construction industry has the highest impact on the environment, ahead of transportation and industrial sectors. 30-40% of energy and material consumption, 35% of landfilled waste generation, and 35% of greenhouse gas emissions are associated with buildings. Many building rating systems have been developed over the past three decades but Leadership in Energy and Environmental Design (LEED) is the most widely used rating system in Canada.*

*Canada presents a wide geographical variation from Atlantic to Pacific Ocean. In this paper, spatial analysis for LEED certified buildings across Canada is performed to investigate and study the relationship of regional characteristics to LEED strategies (points). Results show that only 1% of LEED certified projects are located in Far East provinces. Also, only 2% of LEED certified projects use onsite renewable energy despite the fact that most of regions in Canada have a high photovoltaic potential for solar energy use. The result of this paper can assist in choosing appropriate LEED strategies based on regional characteristics in Canada.*

**Keywords,** *Spatial analysis, green building, LEED, Canada*

### Introduction and Background

The world population is growing and development is a driving force of nations to stay competitive in the modern world. Both population growth and economic development need infrastructure and building support. This led to more construction globally specially in the past decades. It took a while until society became aware of drastic impacts of building and construction industry on environment, society and economy. Studies show that building sector generates biggest amount of CO<sub>2</sub> emission that is more than the emissions produced by other major sectors such as transportation and industry (Energy information administration, 2006). Buildings consume 30-40% of the limited natural reserves on the planet (Roodman and Lenssen, 1995) and are responsible for 40% of global energy consumption (WBCSD, 2007). More than half of landfilled generated waste comes from construction and building activities. (USGBC 2007).

Building sector has a considerable economic footprint in both developed and developing countries. Canadian construction industry contributes has grown more than 40% in the last decade (Statistics Canada, 2011). This economic impact is even higher in developing countries, due to higher demand for building and infrastructures. Statistical data shows that building sector share in GDP is even in developing countries, such as Armenia (19%), Tajikistan (11%), Spain (10%) and Romania (10%) are considerable (UNECE, 2010).



People are in direct interaction with buildings during construction (i.e. construction workers) and operation (i.e. building occupants). This exposure leads to direct impact of indoor environmental quality (both during and after construction) on health, comfort and well-being of building users.

In the past three decades many studies, researches and experiments have been conducted to understand and evaluate the environmental impacts of buildings such as global warming, resource depletion and waste generation and highlighted the need to move toward “green buildings”. There are various definitions for green buildings (also referred to as “sustainable buildings”), but a widely accepted definition of green building is provided by the United States Environmental Protection Agency (US EPA) as “the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction”. (US EPA, 2010).

The current research on green building can be categorized into three groups (Zue and Zhao, 2014):

1. Studies that investigate the benefits of green building and try to answer: why green buildings?
2. Studies that define the boundary for green building and try to answer: what is a green building?
3. Studies that provide metric on how to measure green buildings?

Leadership in Energy and Environmental Design (LEED) is the most widely used rating system in North America, and Canada Green Building Council (CaGBC) has adopted LEED to develop LEED Canada.

LEED is a point-based building rating system developed by the United States Green Building Council (USGBC) in 2000. LEED covers various types of buildings, including, LEED for new construction and major renovation (NC), existing buildings (EB), commercial interior (CI), core and shell (CS), homes (H) and neighborhood development (ND).

LEED-NC (USGBC, 2009) has total of 110 points consist of 100 base points, 6 possible points for innovation in Design and 4 regional priority points. A building may receive different level of certification based on its point scores. The certification levels are:

- Certified 40–49 points
- Silver 50–59 points
- Gold 60–79 points
- Platinum 80 points and above

Buildings are assessed in five main categories for certification, namely:

- Sustainable Sites (SS)



- Water Efficiency (WE)
- Energy and Atmosphere (EA)
- Materials and Resources (MR)
- Indoor Environmental Quality (IEQ)

Design, construction and operation of buildings are under a big influence by their surrounding climate, availability of buildings materials, technology and behavior of people in that region. Despite the significance of regional characteristics, spatial consideration in green buildings lacks largely in the literature (Cidell and Beata, 2009). It is a major drawback to ignore the role of geography in green buildings evaluation considering the variations of environmental conditions around the world and their influence on energy demands and cultural norms (Eliasson, 2000).

In the past decade over 1000 LEED buildings have been certified in Canada, the second highest number in the world. Canada presents a wide geographical variation from Atlantic Ocean to Pacific Ocean. In this paper spatial analysis for LEED certified buildings across Canada is performed to investigate and study the relationship of regional characteristics to LEED strategies (points).

### Methodology

This paper considers 100 LEED building across Canada that received certification under one of LEED version 2009 rating systems, including LEED for New Construction and Major Renovations, LEED for Core and Shell Development and LEED for Retail. The building and certification data were collected from CaGBC project profile database (2014) and USGBC LEED project directory (2014) in May 2014. Complete set of data used for this paper is included in Appendix A. ArcGIS (2014) is used for analyzing and presentation of data. Figure 1 shows location of these LEED certified buildings on a map. All of the maps created for this paper are accessible online through: <http://bit.ly/1gXAqlE>

### Results and Discussion

Spatial patterns of four categories are studies in this paper and discussed in the following sections:

#### *A. Level of LEED certification and number of green buildings across Canada*

Figure 1 shows level of certification of each project across Canada. The area of circle represents the number of points, and the color represents level of certification. Ontario (ON) with 45% of projects has the highest number of LEED certified projects in Canada. Quebec (QC) with 20%, British Columbia (BC) with 15% and Alberta (AB) with 14% are after ON. It is interesting to point out that eastern provinces (Newfoundland and Labrador, New Brunswick, Nova Scotia and Prince Edward Island) account for only 1% of LEED certified projects in Canada.



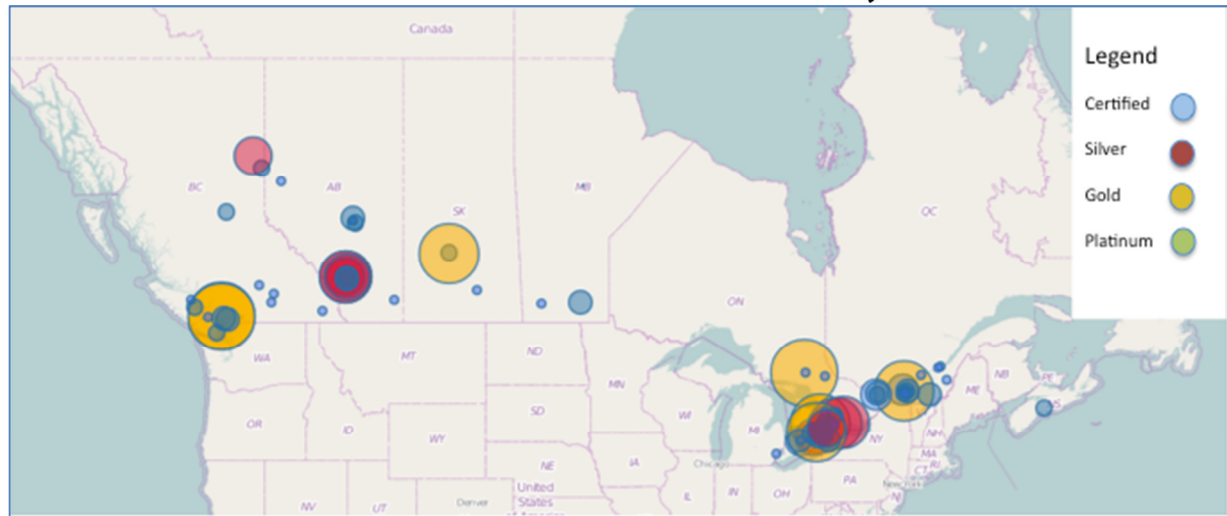


Figure 1. Level of LEED certification across Canada

Majority of the LEED projects are only Certified, 12% of the buildings are Silver (mainly in the ON and QC), 13% are Gold certified and there is no Platinum certified building. In recent years, provincial and federal governments have adopted green building policies. As a result, 60% of Gold certified buildings are owned by university, college, government or the public sector. As it can be seen, the projects that are outside of major cities (lower population, and less income level) and have lower environmental concerns targeted only LEED Certified. Examples are projects in interior BC, AB, Saskatchewan (SK) and Manitoba (MB).

### ***B. Trend of energy saving in buildings across Canada***

In discussions around green buildings, energy saving is the first and most important parameter. Similarly, energy conservation has the highest number of points in LEED rating system. Figure 2 shows number of points awarded by each building for LEED credit EAc1 Optimized Energy Performance.

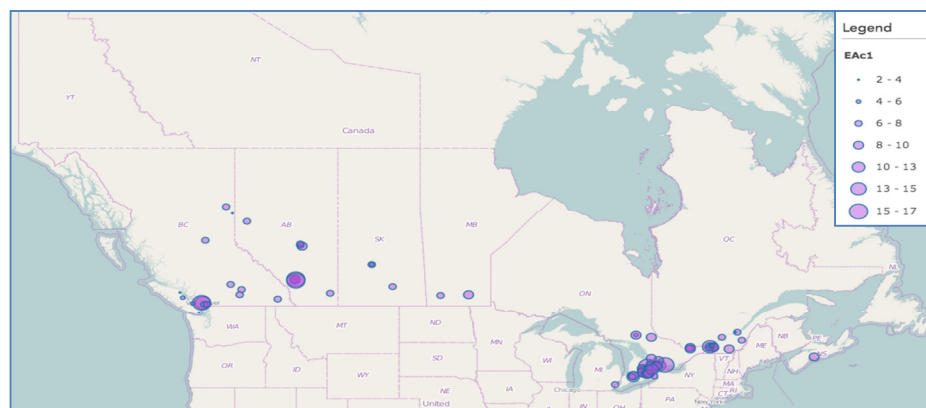


Figure 2. Energy saving in green buildings: LEED EAc1 points

The points are based on energy savings compared to the base building defined by ASHRAE 90.1 (2007) standard, as shown in Table 1.

*Table 1. LEED Points for EAc1*

Points	Energy Savings	Points	Energy Savings
1	12%	11	32%
2	14%	12	34%
3	16%	13	36%
4	18%	14	38%
5	20%	15	40%
6	22%	16	42%
7	24%	17	44%
8	26%	18	46%
9	28%	19	48%
10	30%		

On average, projects in Alberta and Ontario with 28% have the highest energy savings in Canada. Average project in BC saves 24% and in QC saves 22% energy. Two projects, one in Toronto and one in Calgary, have 44% energy savings. The spatial analysis shows that project in suburban and rural areas have less energy savings compared to projects in developed urban areas. This might be due to use of less effective building insulation materials and energy efficient technologies.

Use of onsite renewable energy (LEED credit EAc2) and investment in green power generation off-site (LEED credit EAc6) are among key strategies to reduce the environmental impacts of buildings that rely on grid sources for their energy supply (mainly from non-renewable resources). Figure 3 illustrates these two LEED credits across Canada.

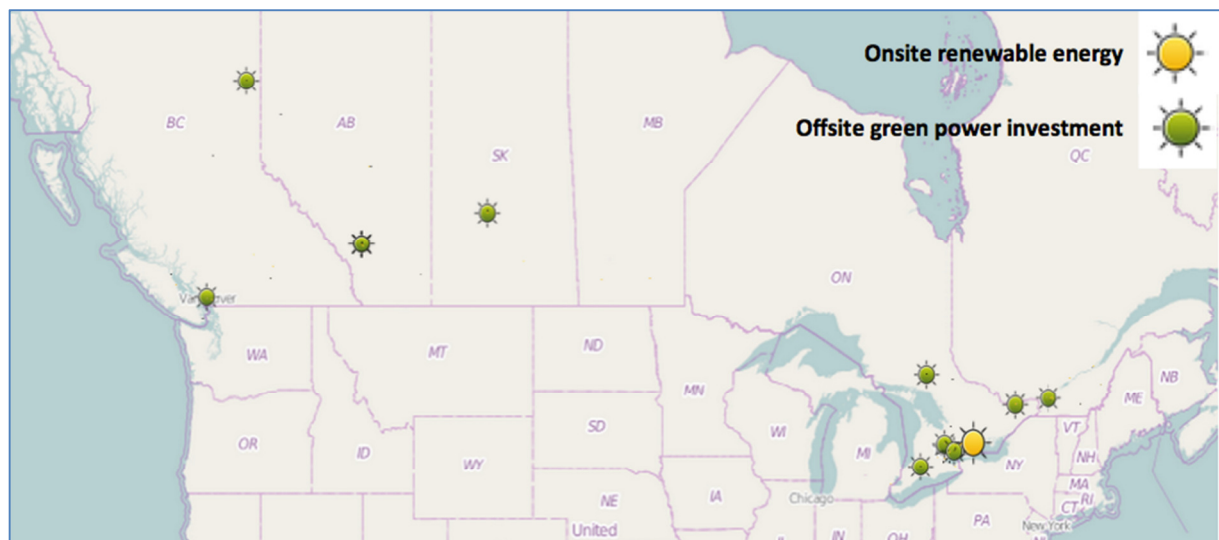
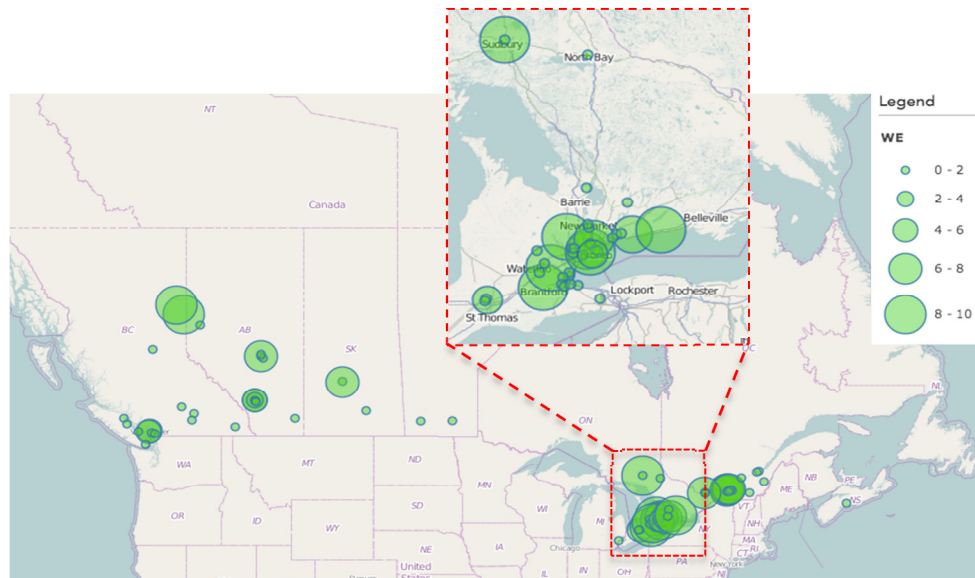


Figure 3. Onsite renewable energy (EAc2) and offsite green power investments (EAc6)

Even though most of regions of Canada have a high photovoltaic potential (kWh/kW) of 1000 to 1400 (NRC, 2014), only 2% of LEED certified projects uses onsite renewable energy. Moreover, only 15% of green building projects across Canada (mainly in metro Toronto region) invest in offsite renewable power generation from wind and solar.

### ***C. Water use reduction across Canada***

Water is a precious resource that is used and wasted in buildings. In this section, water use reduction of LEED certified building is studied. The water savings due to efficient landscaping (LEED credit WEc1), innovative wastewater technologies (LEED credit WEc2) and less use in buildings (LEED credit WEc3) are shown in Figure 4.



*Figure 4. Water use reduction*

Analysis of this study shows that on average LEED certified building in Canada have 30% water savings compared to conventional buildings. Interior regions of BC, AB, MB and SK with 100-200 mm of mean annual precipitation have the lowest amount of precipitation in Canada and water conservation should be more stringent in these regions. However, the spatial analysis shows that LEED certified projects in these regions have least amount of water savings. The highest amount of water saving in buildings occurs in southern Ontario, which also receives one of the highest amounts of precipitation in Canada (800-1200mm) (Atlas of Canada, 2009).

### ***D. Sustainable materials and construction waste reduction across Canada***

Considering that buildings consume 30-40% of the limited natural reserves on the planet (Roodman and Lenssen, 1995), using sustainable materials and construction waste reduction is of key importance in green buildings. Figure 5 shows number of points awarded by LEED projects in Materials and Resources (MR) category.

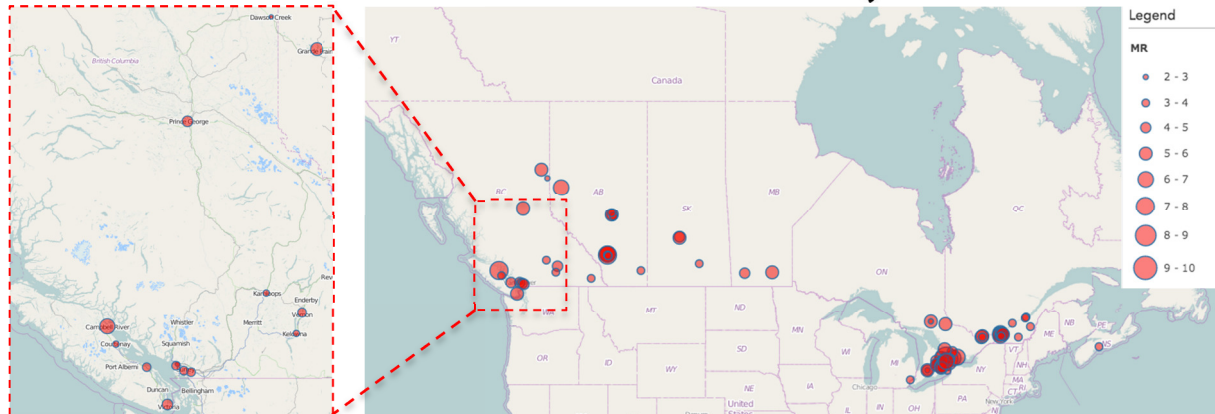


Figure 5. Sustainable materials and construction waste reduction

On average, LEED buildings received 5 points for this category. Buildings in BC have more than 50% diversion rate for construction waste. It is an important achievement noting that more than half of land-filled generated waste comes from construction and building activities. (USGBC 2007). This is due to proper construction waste management programs promoted by Metro Vancouver, City of Vancouver and other local governments in BC.

### Conclusion

This paper studied spatial analysis for 100 LEED certified buildings across Canada to investigate the relationship of regional characteristics to LEED strategies (points). The building and certification data were collected from CaGBC project profile database (2014) and USGBC LEED project directory (2014) in May 2014.

Results show that only 1% of LEED certified projects in Canada are located in eastern provinces of Newfoundland and Labrador, New Brunswick, Nova Scotia and Prince Edward. Also, only 2% of LEED certified projects use onsite renewable energy despite the fact that most of regions of Canada have a high photovoltaic potential for solar energy use. Moreover, only 15% of green building projects across Canada (mainly in metro Toronto region) invest in offsite renewable power generation from wind and solar. In addition, Interior regions of BC, AB, MB and SK with the lowest amount of precipitation in Canada have the least amount of water savings.

Result of the spatial analysis in this study shows that Canada has a high geographical potential that can be used strategically to reduce the impacts of buildings. However, LEED certified buildings do not fully take advantage of these resources, and are not designed based on the needs of their region. The result of this paper can assist in choosing appropriate LEED strategies based on regional characteristics in Canada.

### References

ASHRAE (2007). *ASHRAE 90.1-2007: Energy Standard for Buildings Except Low-Rise Residential Buildings*.



Atlas of Canada (2009). *Annual mean total precipitation in Canada*. Retrieved on May 13, 2014 from

[http://atlas.nrcan.gc.ca/data/english/maps/water/annual\\_mean\\_total\\_precipitation\\_map.pdf](http://atlas.nrcan.gc.ca/data/english/maps/water/annual_mean_total_precipitation_map.pdf)

Canada Green Building Council (2014). *LEED Projects profile*. Accessed on May 2, 2014.

Chew, M. Y. L. & Das, S. (2007). Building grading systems: a review of the state-of-art. *Architectural Science Review*, 51 (1), 3-13.

Energy information administration (2006). *Emission of greenhouse gases in the United States*.

Esri (2014). *ArcGIS*. Accessed on January 20, 2014

Natural Resources Canada (NRC) (2014). *Photovoltaic potential and solar resource maps of Canada*. Retrieved May 17, 2014 from <http://pv.nrcan.gc.ca/index.php?m=r>

Roodman, D. M. & Lenssen, N. (1995). *A building revolution: how ecology and health concerns are transforming construction*. Worldwatch Institute.

Statistics Canada (2011). *Canadian building construction*. Retrieved December 02, 2011, from <http://www.statcan.gc.ca/pub/11-402-x/2010000/pdf/construction-eng.pdf>

UNECE, 2010. *Share of construction in GDP*. Retrieved December 12, 2013, from [http://w3.unece.org/pxweb/quickstatistics/readtable.asp?qs\\_id=8](http://w3.unece.org/pxweb/quickstatistics/readtable.asp?qs_id=8)

U.S. Green Building Council (USGBC) (2007). Retrieved December 02, 2011, from [www.usgbc.org/showfile.aspx?documentid=742#8](http://www.usgbc.org/showfile.aspx?documentid=742#8)

US Green Building Council (2009). *LEED for new construction and major development*. Washington DC: USGBC.

US Green Building Council (2014). *LEED projects directory*. Accessed on May 1, 2014.

U.S. Environmental Protection Agency (US EPA) (2010). *Green building basic information*. Retrieved November 14, 2011, from: <http://www.epa.gov/greenbuilding/pubs/about.htm>

WBCSD (2007). *Energy efficiency in buildings, business realities and opportunities*. The World Business Council for Sustainable Development.

Zuo J., Zhao, Z.Y. (2014). Green building research—current status and future agenda: A review. *Renewable and Sustainable Energy Reviews* (30) 271–281



## Practical limitations in Embodied Energy and Carbon measurement, and how to address them: a UK case study

### Speakers:

Gavotsis, Efstratios<sup>1</sup>; Moncaster, Alice<sup>2</sup>

<sup>1</sup> Building Structures, Ramboll & Department of Architecture, University of Cambridge, London, United Kingdom

<sup>2</sup> Director, IDBE Masters Course, Departments of Engineering and Architecture, Fellow, College Lecturer and Director of Studies in Engineering, Newnham College, Cambridge, United Kingdom

**Abstract:** *The built environment is blamed for producing the majority of carbon emissions. While policy remains focused on emissions during the operational phase, research demonstrates that embodied impacts are a significant proportion of whole life ones. This paper presents a case study of a building that integrates low-energy design features. The study was carried out during the construction phase enabling superior quality of data to be collected. The cradle-to-grave embodied impacts were modelled to the TC350 Standards using an innovative tool, and the operational impacts through simulation, incorporating future climate predictions. In spite of the data quality, the study demonstrates a high level of uncertainty due to a number of industry-wide issues. This paper identifies these issues and concludes that considerable barriers to measuring embodied impacts remain. Key recommendations are made for industry and policy, in order to gear up the measurement and reduction of embodied impacts of buildings.*

**Keywords:** *embodied, energy, carbon, sustainable building, construction, energy assessment*

### 1 Introduction

The built environment accounts for approximately 40% of the world's total energy consumption (1). The latest regulations (2) demand that buildings produce zero net operational CO<sub>2</sub>(e) emissions in the near future. Nevertheless, this strategy omits the Embodied Energy and Embodied Carbon (EE&EC) which constitute a considerable amount of the building total energy and carbon (E&C) of the building (2%-46%) with values up to 500MJ/m<sup>2</sup>/year (3,4). The inclusion of those burdens is not currently a legislative requirement and only voluntary standards, such as the European TC350, "the basis of measuring embodied energy and carbon in products and projects" (5) in the UK, exist. On the other hand, there are a number of studies of individual buildings, but the inconsistencies and variations make comparison between them difficult (6). Also, it has been proved that the error in any typical embodied energy analysis may be as high as 20% (7) with 50% incompleteness for the process-based method (8). This method is also used by the TC350 standards and is "extremely complex and time-consuming" (6). To understand the issues and barriers that arise during the calculation process of the embodied energy and carbon, a school building in Cambridge, UK was chosen as a case study. There was collaboration and keen interest from all parts, leading – it would be assumed- to easily accessible data. The "Ecoclassroom" integrates low-energy features and makes extensive use of local workforce, environmentally friendly materials and sustainable construction methods while it has been designed to withstand 2080 conditions.

## 2 Methodology and results

The research deployed different methods to answer the questions posed. In the centre lies the case study, supported by simulation, observation and interviews. The boundaries of the investigation are shown below (Table 1). There are, as expected, limitations such as the future decarbonisation of UK mix, which was not accounted for. Also, when information about the CO<sub>2</sub>(e) emissions was unavailable, the CO<sub>2</sub> data was used (9).

Building Assessment Information														
Building Life Cycle Information														Beyond Building Life Cycle
Product Stage			Construction Process Stage		Use Stage					End of Life				Benefits and Loads
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Raw material supply	Transport	Manufacturing	Transport	Construction-Installation process	Use	Maintenance	Repair	Refurbishment	Replacement	Deconstruction/Demolition	Transport	Waste processing	Disposal	Reuse, Recovery, Recycling Potential
					B6	Operational energy use								
					B7	Operational water use								

Table 1: The boundaries of the investigation (highlighted) [from BSEN15978:2011 (12)]

The EE&EC in the infrastructure, fuel processing, power plants and distribution systems was not included. The calculation was conducted using an in-house tool due to reasons that have been mentioned by others (10). Concerning operational energy, it was not possible to measure it and therefore simulations were run using DesignBuilder, a dynamic simulation software, incorporating 2080 climate predictions (11).

The absolute energy values for the whole lifecycle were within the range reported by other studies for low energy buildings (3,4). For operational energy, results were in good proximity with those of the building services engineers (8% difference).

The calculation resulted in a total of 7239GJ primary energy for its lifecycle, equal to 622MJ/m<sup>2</sup>/year (68 years, till 2080) (Figure 1). The respective values for carbon were estimated to rise to 39kgCO<sub>2</sub>(e)/m<sup>2</sup>/year. The ratio of embodied to operational energy (EE, OE) was approximately equal to 1:2 and the respective one for carbon equal to 1:1.5.

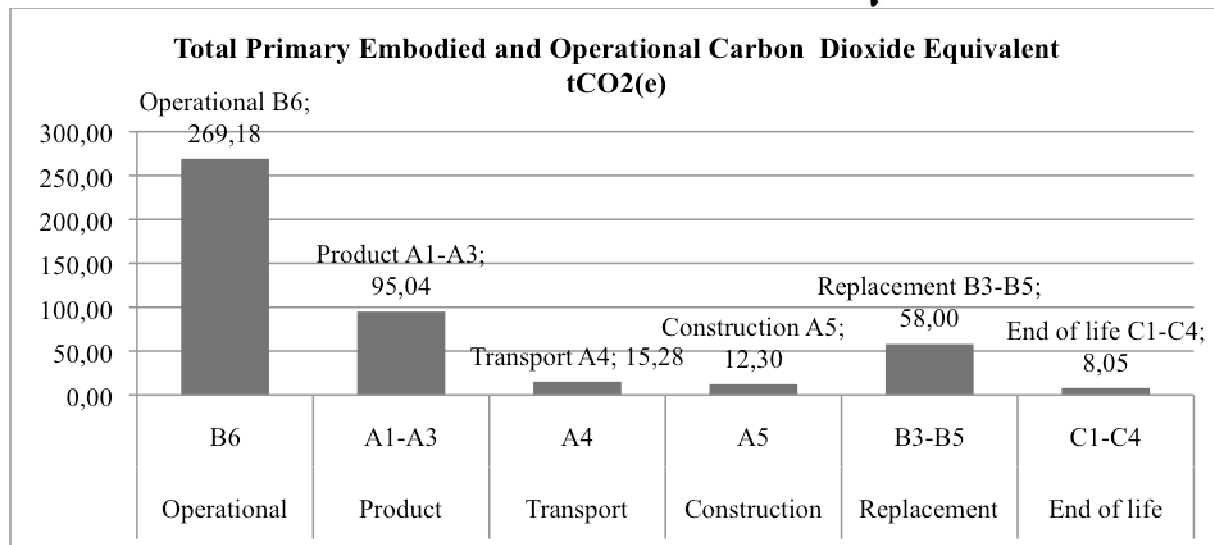


Figure 1: Total lifecycle carbon dioxide equivalent breakdown (tCO<sub>2</sub>e/m<sup>2</sup>/y)

### 3 Issues faced during the process

In spite of the data quality, the case study demonstrates a high level of uncertainty for the calculation of Embodied Carbon and Energy at each lifecycle stage. The main reasons are outlined below:

#### 3.1 Lack of a data collection method for stages A1-A5

There was no standard method for the collection of data concerning the type, number and specifications of components used in a building, their transport to the site, the construction energy, the waste and their destination. The collection of data depended on personal relationships and the time since completion of the project. The speed and quality of data collection was hampered by the subcontracting culture leading to missing data, estimated by the author to be as high as 10-30% on both EE&EC. For the product stage, the study followed a number of successive ways to gather accurate and complete data, including the use of delivery tickets and drawings, contractor estimations and interviews, correspondence with manufacturers and site visits. Despite the effort, a number of components were: not identified at all; identified but out of scope; identified but not calculated because of their size or complexity; identified but not calculated due to the lack of information or identified but roughly estimated. It was calculated that if the calculation had been based only on the initial list given to the authors by the contractor, the EE values for stages A1-3 and A4 would have been underestimated by 33% and 50%. The respective underestimation for the replacement stage would have been 32%. These changes have impacts on the construction and demolition EE&EC too through the calculation of waste materials. The total underestimation would have been 30% and 25% for EE and EC, respectively.

Concerning transport, most components were either manufactured in the UK or imported from Europe. Some suppliers provided information concerning the means of transport and the route followed. The distance from the factories to the distribution centres and the final site was calculated using Google Maps. When information was not available for the means of



transport, the most reasonable approach was followed. The transportation of the construction equipment to and from the site was also included, although this was a very small amount.

Finally, the Construction module A5 was given by the following components:

Production and transportation of materials lost or damaged during construction. The contractor was unable to specify the exact quantities thrown to waste and the waste management company was reluctant to share any information. There are different approaches on how to calculate the impact [e.g. (13,14)]. In this research, it was calculated as the fraction of the mass of waste to the total mass of initial materials, multiplied by the total E&C contribution of the A1-4 stage.

Construction Energy. Energy was consumed mainly at three sources: the diesel consumed on site, the school electricity consumption and the manufacturers. For the first, a crude estimation was provided by the contractor and for the second the consumption for the previous and next year were compared with that of the construction year (2012). Only the timber-frame subcontractor was able to provide approximated data corresponding to the off-site construction.

Waste (downstream):

The final on-site construction waste volume was calculated indirectly through the number of skips used but, their exact composition and mass were unknown and therefore were calculated based on pro-rata values by two reports (15,16). Only the transport of the muck-away (uncontaminated soil) and the on-site construction waste to the final site was included in the calculation. Neither the waste processing nor the disposal was included due to limited data. For the off-site waste, information was requested from the factories but -again- only the timber factory management could provide some information.

### **3.2 Lack of published figures for embodied impacts of components**

The actual environmental impacts could only be calculated for a limited number of components as there is currently no established culture for the creation of Environmental Product Declarations (EPDs). The calculation of the EE&EC impacts of the components was conducted using inventories (9,17) and a few EPDs (only 5 out of almost 200 products identified). For some composite components, it was necessary to approximate the contribution of the constituent materials, when this was not available from the manufacturer. The transport factors used were taken from a tool (17) that uses UK and European values that have been adapted to include the empty return journey. When information on the method of transport was not available for short distances, the rigid heavy-goods vehicle was chosen to provide a good approximation. The mean of transport for the construction equipment was assumed to be the “articulated Heavy Goods Vehicle”.

### **3.3 Uncertainties for post-construction stages**

The calculation of the Use stage was based on approximations that might over-/underestimate the contribution of an element. If the life expectancy of the component was small, a

replacement was assumed to be carried out. Replacement factors have been suggested [e.g (19)] but, they refer to assemblies rather than components. Instead, the authors used a report by the NAHB (20), few product specifications and design team estimates to calculate the component life expectancy. This report however, is intended for residential buildings and the replacement values might be underestimated for a classroom. The production and transportation was assumed to be similar to modules A1-4, while the construction energy was equated to the fraction of the energy and carbon impact of the specific component in the A1-3 stage to the total impact of stage A1-3, multiplied with the total construction energy A5. The impacts of excessive materials used during replacement were not included, as there was no relevant data. The total mass of waste was equal to the replaced components and only transport was included.

Previous research concerning the demolition, waste processing and loads and benefits beyond the building lifecycle is limited (18). For the End of life stage, the authors used the values of Moncaster and Symons (17) for the calculation of the deconstruction/demolition phase (C1), as it is recent and UK-relevant. The demolition waste was assumed equal to the original mass of components and only its transport was included in the final impact.

Carbon Sequestration was commented separately and was not included in the final carbon bill. It was equal to 5.9% of the whole life carbon. This was only related to wasted timber from all stages and none of its by-products. Since some building components were only 70% certified, a common approach of 70% sustainable timber was followed. The calculation was based on a paper by Symons et al. (21) who assume removal and storage of 1.8kgCO<sub>2</sub>/kg-wood from the atmosphere. The total burden or benefit depends on the final destination of this timber. It was assumed that 33.3% was sent to Landfill and that the rest 66.6%, was reused/recycled. The mass wasted at the timber-frame factory was all recycled.

### **3.4 Varied boundaries, multiple calculation methods**

Existing standards present differences in the method they follow, the boundaries, and the contribution and responsibility of each industry sector (10). For example, had this study been based on stages A1-3 only, as advised by some standards and the government (5,12), the embodied impacts would have been underestimated by approximately 50%. Furthermore, a common approach is missing in terms of the assemblies and components included in the calculation (22). Also, TC350 standards have inherent weaknesses (e.g. process-based method, omission of the impacts of the designer's offices, infrastructure, etc) that should be considered.

### **3.5 Limited knowledge dissemination**

The strategic decisions of clients, designers and contractors affect not only the current but also the future EE&EC of a building. Despite the fact that the shareholders for this case study were all informed on the importance of EE&EC, most of the industry is not and their understanding is mostly based on the initial stages (A1-3) and common perception.



#### **4 Conclusion and discussion**

Five important difficulties were faced in the process of calculating the EE&EC of this classroom. To overcome these, it is vital to create a digital database for the collection of post-construction information on EE&EC that will give each building an “Identification” and boost research. Existing databases should be enriched and updated to include more materials and especially composite components. These should be publicly available and protected from industry interests, leading to a UK National database. EPDs should be obligatory and include all lifecycle stages since the relative impact of these changes within the building lifecycle and more research should be conducted for post construction stages (i.e. use, end-of-life and beyond the building lifecycle stage). Moreover, there should be an agreement on the standard, the boundaries and the method used for the calculation of EE&EC and similar measures to the ones taken to decrease operational energy and carbon should be launched. It also needs to be clear which assemblies will be used in calculations across the UK to allow direct comparison amongst studies conducted using the same standards. Finally, all parties involved in construction should be well informed on embodied impacts ahead of the project initiation.

More than a third of the whole life energy expenditure & carbon emissions are likely to come from the embodied energy and embodied carbon (EE&EC), based on this study. Current standards and policies only encourage and do not regulate the calculation of a part of these. With the development of EU and global standards defining the methodology for measuring EE&EC, and increasing evidence that it is a significant proportion of the whole life impacts for a building, it is now time for the calculation of cradle-to-grave/cradle EE&EC impacts to be legislated. There are many alternatives for how this could become reality by, for example, creating a system similar to the one used by SAP and SBEM where a “standard” building is compared with the actual one. Another way forward would be to agree on an absolute value, depending on the type of the building. This will put considerable pressure on the industry to accelerate changes towards becoming more sustainable. This target/limit could also lead to a complete building rating system for E&C as some of the most advanced systems (e.g. BREEAM) include EE&EC impacts for a number of components but omit other, extremely important ones, such as building services.

#### **References:**

1. United Nations. (2009). United Nations Environment Programme (UNEP) - Buildings and Climate Change, Summary for Decision Makers. Retrieved May 6, 2013, from <http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf>
2. The European Parliament, & The Council of the European Union. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). , L153/13 23 (2010). Retrieved from <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF>
3. Ramesh, T., Prakash, R., & Shukla, K. K. (2010). Life cycle energy analysis of buildings: An overview. *Energy and Buildings*, 42(10), 1592–1600.doi:10.1016/j.enbuild.2010.05.007
4. Sartori, I., & Hestnes, A. G. (2007). Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings*, 39(3), 249–257.doi:10.1016/j.enbuild.2006.07.001



5. HM Government. (2010). *Low carbon construction innovation and growth team-Final report*. Retrieved from <http://www.bis.gov.uk/assets/biscore/businesssectors/docs/l/10-1266-low-carbon-construction-igt-final-report.pdf>
6. Dixit, M. K., Fernández-Solís, J. L., Lavy, S., & Culp, C. H. (2010). Identification of parameters for embodied energy measurement: A literature review. *Energy and Buildings*, 42(8), 1238–1247. doi:10.1016/j.enbuild.2010.02.016
7. Langston, Y. L., & Langston, C. A. (2008). Reliability of building embodied energy modelling: an analysis of 30 Melbourne case studies. *Construction Management and Economics*, 26(2), 147–160. doi:10.1080/01446190701716564
8. Lenzen, M., & Treloar, G. (2002). Embodied energy in buildings: wood versus concrete—reply to Börjesson and Gustavsson. *Energy Policy*, 30(3), 249–255. doi:10.1016/S0301-4215(01)00142-2
9. Hammond G. P., & Jones C. I. (2008). Embodied energy and carbon in construction materials. *Proceedings of the ICE - Energy*, 161(2), 87–98. doi:10.1680/ener.2008.161.2.87
10. Moncaster, A. M., & Song, J.-Y. (2012). A comparative review of existing data and methodologies for calculating embodied energy and carbon of buildings. *International Journal of Sustainable Building Technology and Urban Development*, 3(1), 26–36. doi:10.1080/2093761X.2012.673915
11. Future weather files - University of Exeter. (n.d.). Retrieved June 17, 2013, from <http://emps.exeter.ac.uk/research/energy-environment/cee/projects/prometheus/termsandconditions/futureweatherfiles/>
12. British Standards Institution: London. (2011). *British Standards Institution, BS EN 15978, Sustainability of Construction Works-Assessment of environmental Performance of Buildings-Calculation Method*. BSI. Retrieved from <http://shop.bsigroup.com/ProductDetail/?pid=000000000030256638>
13. Gustavsson, L., Joelsson, A., & Sathre, R. (2010). Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building. *Energy and Buildings*, 42(2), 230–242. doi:10.1016/j.enbuild.2009.08.018
14. Blengini, G. A. (2009). Life cycle of buildings, demolition and recycling potential: A case study in Turin, Italy. *Building and Environment*, 44(2), 319–330. doi:10.1016/j.buildenv.2008.03.007
15. Department for Environment, Food and Rural Affairs (DEFRA), AEA Technology, & British Research Establishment (BRE). (n.d.). *Developing a strategic approach to construction waste. 20 year strategy draft for comment*. (p. 22). Retrieved from <http://www.bre.co.uk/filelibrary/pdf/rpts/waste/ConstructionWasteReport240906.pdf>
16. British Research Establishment (BRE). (2012). *SmartWaste Plan-BRE waste benchmark data*. Retrieved from [http://www.smartwaste.co.uk/filelibrary/benchmarks%20data/Waste\\_Benchmarks\\_for\\_new\\_build\\_projects\\_by\\_project\\_type\\_31\\_May\\_2012.pdf](http://www.smartwaste.co.uk/filelibrary/benchmarks%20data/Waste_Benchmarks_for_new_build_projects_by_project_type_31_May_2012.pdf)
17. Moncaster, A. M., & Symons, K. E. (2013). A method and tool for “cradle to grave” embodied carbon and energy impacts of UK buildings in compliance with the new TC350 standards. *Energy and Buildings*, 66, 514–523. doi:10.1016/j.enbuild.2013.07.046
18. Monahan, J., & Powell, J. C. (2011). An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. *Energy and Buildings*, 43(1), 179–188. doi:10.1016/j.enbuild.2010.09.005
19. Thormark, C. (2002). A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential. *Building and Environment*, 37(4), 429–435. doi:10.1016/S0360-1323(01)00033-6



20. Economics group of NAHB. (2007). *Study of life expectancy of home components*. National Association of Home builders/Bank of America Home Equity. Retrieved from [http://www.nahb.org/fileUpload\\_details.aspx?contentID=99359](http://www.nahb.org/fileUpload_details.aspx?contentID=99359)
21. Symons KE, Moncaster AM, & Symons D. (2013). An application of the CEN TC350 standards to an Energy and carbon LCA of timber used in construction, and the effect of end-of-life scenarios. Presented at the Australian Life Cycle Assessment Society (ALCAS) conference, Sydney, Australia: Unpublished.
22. Cole, R. J., & Kernan, P. C. (1996). Life-cycle energy use in office buildings. *Building and Environment*, 31(4), 307 – 317. doi:[http://dx.doi.org/10.1016/0360-1323\(96\)00017-0](http://dx.doi.org/10.1016/0360-1323(96)00017-0)

## A metaheuristic approach for heat pump scheduling

Schütz, Thomas<sup>1</sup>; Streblow, Rita<sup>1</sup>; Müller, Dirk<sup>1</sup>

<sup>1</sup> RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate, Aachen, Germany

**Abstract:** *A reduction of the primary energy consumption (PEC) for heating purposes is a key measure for meeting the German government's climate protection goals of reducing greenhouse gas emissions. Heat pumps are widespread heating devices that are typically installed together with thermal storages. This combination allows for a high scheduling flexibility that can be exploited for optimization purposes.*

*In this work, a methodology for optimally scheduling monovalent heat pumps is presented. The methodology combines the advantages of metaheuristics and deterministic mixed-integer linear programming to improve the computational efficiency of the applied metaheuristic algorithm. This methodology is further investigated using a case study that comprises an apartment building and a monovalent heat pump system. The results indicate that this approach is able to reduce the PEC and resulting costs significantly.*

**Keywords:** *Scheduling, metaheuristic, population-based incremental learning (PBIL), optimization, heat pump*

### Introduction

The transition towards a more energy efficient and environmental-friendly economy is a recognized objective for most developed countries. In Germany, this concept is known as “Energiewende” and aims at reducing the electricity consumption, increasing electricity generation from renewable energy sources, and reducing greenhouse gas emissions [1].

In this work, a method for optimally scheduling heat pumps in monovalent heating systems, with the objective of minimizing the primary energy consumption (PEC) is presented. Applications of this method are primarily the industrial sector, in which the heating demand can be predicted precisely, as well as decentralized scheduling in future smart grids.

Heat pumps are nowadays installed in roughly one third of all new single-family dwellings in Germany [2] and are becoming more popular in industry applications, as environmental regulations and energy prices increase [3]. Thus, heat pumps pose large potential for energy savings. Typically, heat pumps are coupled with a thermal storage unit in order to increase the heating device's runtime and reduce the amount of load cycles. Moreover, thermal storage units decouple the heat demand from the generation, therefore providing flexibility in the scheduling of the heat generator. This flexibility can be exploited for optimizing the heat pump's operation.

These scheduling and heating system optimization problems have been solved through many different approaches. Especially for less detailed models, mixed-integer linear programming (MILP) is applied, like [4] showed for the unit commitment problem. In more detailed mod-

els, metaheuristics are typically used. For example, [5] utilized a metaheuristic approach for determining a set of optimal operating parameters for heat pumps.

Like [6] and [7], this paper also uses simulation software to simulate building and heating system and couples this software with a metaheuristic optimization algorithm. Instead of completely relying on the metaheuristic, as done in these sources, a deterministic, mixed-integer linear program is utilized to obtain a good initial solution and thus guide the metaheuristic into promising regions of the search space.

In the following section, the methodology is described in more detail. The next section outlines the investigated case study; the results are explained subsequently. Finally, a summary and an outlook are presented.

### Methodology

The general concept of the optimization approach is shown in figure 1. First, a typical heat-driven simulation is carried out, to compute the building's heat demand and the characteristics of the heat pump at each time step, which are input parameters for the mixed-integer linear program. The resulting schedules of the heat-driven simulation and the MILP computation are forwarded to the metaheuristic (PBIL) [8]. The schedule with the better objective value is further used in PBIL. This metaheuristic then generates schedules and computes their objective values by executing the simulation until the optimum is found.

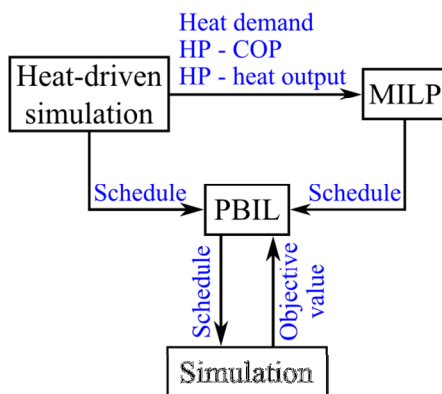


Figure 1: General concept of the optimization process

This paper considers heat pumps as two-point controllers that either run at nominal load or are turned off. Also, a time discretization of 15 minutes is used, resulting in 35040 time steps per year. Since this amount of binary variables cannot be handled efficiently, a rolling wave planning is employed, in which every 24 hours a schedule for the upcoming 48 hours is computed. In this manner, each scheduling problem is reduced to 192 binary variables, which is a suitable size for the PBIL algorithm [8].

The building and heating system are modeled in Modelica<sup>®</sup> and simulated with Dymola<sup>®</sup>. The building model was developed by [9] and is an extension of VDI guideline 6007. The model is a low order thermal network model, in which the building's thermal zones are represented as thermal resistances and capacitances. The model was initially extended to be suitable for



simulating city districts; therefore, its computational procedure is very efficient, making it appropriate for coupling in an iterative optimization process.

The heating system consists of an air-water heat pump and a stratified storage. Domestic hot water is currently neglected. A black box approach is proposed by [10], where the power input and heat output are determined by manufacturer data that are interpolated based on current operating temperatures. The thermal storage is modeled as a one-dimensional concatenation of homogeneous fluid layers [11]. Buoyancy is treated by considering the temperature gradient between the layers.

In the heat-driven simulation, the heat pump is controlled by the storage's top layer temperature, resulting in a characteristic hysteresis curve. If this temperature drops below the temperature determined by the heating curve, the heat pump is activated. Analogously, if the flow temperature exceeds the heating curve, the heat pump is deactivated.

The resulting heat demand of the building, as well as the heat pump's coefficient of performance (COP) and heat output are forwarded to a simplified, deterministic optimization model written in GAMS<sup>®</sup> and solved with CPLEX<sup>®</sup>. The objective function of this MILP is the minimization of the heat pump's PEC; in other words, the heat pump is scheduled to require a minimum amount of electricity. The restrictions ensure that the building's heating demand is fulfilled and that the thermal storage's capacity is obeyed at all time steps. A detailed description of the implemented MILP can be found in [12]. The resulting heat pump schedule serves as a second initial solution that is supposedly closer to the global optimum of the scheduling problem, because the MILP and the subsequent metaheuristic approach have similar objective functions.

In this paper, PBIL is chosen as metaheuristic to optimize the initial solution generated by the MILP optimization, resp. the heat-driven simulation. PBIL has been developed by [8] and is a type of genetic algorithm designed for binary optimization problems. [13] has demonstrated that PBIL outperforms standard genetic algorithms on many benchmark problems with up to 2040 variables.

PBIL starts by initializing a probability vector  $P$  with 0.5 in each component. Subsequently, samples are generated with  $P$  and evaluated based on the objective function. Afterwards,  $P$  is updated towards the best investigated sample solution and away from the worst. Finally,  $P$  is randomly mutated to prevent being stuck in local optima. This procedure continues, until a termination condition is reached. A more detailed description of PBIL can be found in [8].

In contrast to the standard PBIL algorithm, the initial solutions of the heat-driven and MILP computation are incorporated by updating the initial probability vector towards the solution with the better objective value.

The metaheuristic algorithm is coupled with a similar model that is used for the heat-driven simulation, except that the internal heat pump controller is replaced by the external signal computed via the PBIL algorithm.

### Objective functions

In this paper, three different strategies are compared. These strategies are the described heat-driven scheduling, the minimization of the PEC, and a minimal cost strategy.

The objective function used in the minimal PEC strategy comprises two different components. The first component is the PEC, which considers the electricity usage of the heat pump. The PEC can thusly be computed as follows:

$$PEC = \frac{1}{\eta_{el}} \cdot \sum_{t=1}^{192} P_{el}(t) \cdot x(t) \quad [1]$$

In equation (1),  $P_{el}(t)$  represents the nominal electricity consumption of the heat pump at time  $t$ ,  $x(t)$  denotes the binary decision variable that equals one if the heating is used at time  $t$  and zero otherwise. In this equation,  $\eta_{el}$  stands for the electrical efficiency of power plants and is set to 42 %.

The second component of the objective function incorporates the predicted percentage of dissatisfied people (PPD), a quantification of the thermal comfort of indoor environments. The PPD considers the mechanical work, metabolic rate and clothing factor of the person as well as the air temperature, mean radiant temperature, air velocity, and the relative humidity in the room [14]. A low value of the PPD indicates comfortable environments. The index range is defined from 5 to 100 %. According to [14], a PPD value above 30 % indicates an unsatisfactory thermal comfort.

In this paper, we assume a constant relative humidity of 50 %, air velocity of  $0.1 \text{ ms}^{-1}$ , and an inactive person with a metabolic rate of 70 W.

A Lagrange formulation [15] is used to combine both components into one objective function that is minimized. The penalty costs describe how often the PPD exceeds a value of 10. These costs are weighted with the PEC of the heat-driven simulation ( $PEC_{hd}$ ). The objective function therefore becomes:

$$\min PEC + PEC_{hd} \cdot \sum_{t=1}^{192} [PPD(t) > 10] \quad [2]$$

The minimal cost strategy (*Min Costs*) is methodologically very similar to the minimization of the PEC (*Min PEC*), only that the objective function is altered to consider costs instead of PEC:

$$\min \sum_{t=1}^{192} c(t) \cdot P_{el}(t) \cdot x(t) + \sum_{t=1}^{192} c(t) \cdot P_{el,hd}(t) \cdot x_{hd}(t) \cdot \sum_{t=1}^{192} [PPD(t) > 10] \quad [3]$$

In equation [3],  $c(t)$  stands for the electricity operating price at time  $t$ .

If the PEC of the heat-driven simulation ( $PEC_{hd}$ ) equals zero, the optimization terminates and the heat-driven schedule is already the (global) optimum for this period.

### Case study setup

The described methodology is applied to an apartment building with a nominal heat load of 50 kW. The building uses a radiator heating system with a nominal flow temperature of 55 °C and a nominal return temperature of 45 °C at 20 °C room temperature. A thermal storage with 1 m<sup>3</sup> volume is chosen for the heating system. The weather conditions are taken from a test reference year for the German city of Bottrop. The investigated time span is ten days, beginning with January 1<sup>st</sup>.

For the heat-driven and minimum PEC strategy, the same operating prices are used. The minimum costs strategy utilizes a special heat pump tariff, offered by many German energy suppliers. All prices are taken from [16] and are shown in table 1.

	Heat-driven	Min PEC	Min Costs
Electricity price in €/kWh	0.2812	0.2812	0.2316 (4:30 AM – 10:30 PM) 0.1962 (10:30 PM – 4:30 AM)

Table 1: Electricity prices, [16]

### Case study results

The ecological, economical and comfort results of the case study are shown in table 2. For computing the CO<sub>2</sub> emissions in each control strategy, an average of 0.601 kg of CO<sub>2</sub> per kWh electricity is used, which is approximately the CO<sub>2</sub> output of the German electricity mix.

Table 2 suggests that both, a cost-driven and a primary-energy-consumption-driven optimization offer large potential for possible cost reduction and increased energy efficiency compared with the standard heat-driven operation of heating systems. The minimization of the PEC leads to a reduction of about 34 % PEC compared with the heat-driven case. Consequently, the costs and greenhouse gas emissions are also reduced by 34 %. The cost minimization also offers large improvements concerning PEC, CO<sub>2</sub> emissions and costs. The costs are reduced by about 42 % while the PEC and consequently CO<sub>2</sub> emissions are cut by 27 %. The optimized schedules result in a marginally higher average PPD value than the heat-driven strategy. The results for the min PEC and min costs strategy still provide a highly satisfactory indoor environment.

	Heat-driven	Min PEC	Min Costs
PEC in kWh	4615	3027	3429
Total costs in €	545.05	357.51	318.69
CO <sub>2</sub> emissions in kg	2774	1819	2061
Average PPD [no unit]	5.13	6.50	5.72

Table 2: Economical, ecological and comfort results

Both optimization strategies schedule the heat pump to run during lucrative time steps, for example the cost minimization shifts the heat pump's operation towards nightly hours, in or-

der to profit from reduced electricity costs. The PEC minimization on the other hand, shifts the schedule towards higher ambient temperatures, because the heat pump's coefficient of performance increases as a consequence of a reduced temperature lift.

Table 3 compares the initial solutions of the MILP model and the heat-driven simulation with a randomly computed initial schedule. The findings suggest the benefits of putting additional effort into the computation of starting solutions. The heat-driven simulation is able to reduce the starting objective value to 0.34 in the Min PEC case and 0.40 in the Min Costs case. A further reduction is achieved by applying the MILP model. The objective value can thusly even be reduced to 0.31 for the Min PEC strategy, resp. 0.35 for the Min Costs strategy.

	Min PEC	Min Costs
Objective values <sup>MILP</sup> /Random	0.31	0.35
Objective values <sup>Heat-driven</sup> /Random	0.34	0.40

*Table 3: Comparison of the objective values of heat-driven and MILP initial schedule*

### Summary and outlook

In this work, a methodology is introduced for optimally scheduling monovalent heat generators. The process starts with a heat-driven simulation which is used as input for a deterministic mixed-integer linear program. The resulting schedule is subsequently used as initial guess for a metaheuristic algorithm. In this manner, a good starting point is found, thus the computational effort for covering the search space is reduced, compared with a random initial guess, which is typically applied.

The methodology is applied to a time span of ten winter days for a multi-family dwelling. The results indicate that the heat-driven operation of the heating device is not optimal and poses large potential for both, energy as well as cost savings. The minimization of the PEC leads to economical and ecological improvements of about 34 %. A cost optimization is shown to reduce the ecological costs of PEC and greenhouse gas emissions by about 27 % and monetary costs by even 42 %.

In future works, the approach could be expanded to include more flexible, modulatable heating devices. Also, the stability of the given schedule for different user behavior and therefore changing heating demand can be examined more intensively.



## References

- [1] BMWi (2012). Die Energiewende in Deutschland. Mit sicherer, bezahlbarer und umweltschonender Energie ins Jahr 2050.
- [2] Shell, BDH (2013). Hauswärme-Studie. Klimaschutz im Wohnungssektor – Wie heizen wir Morgen?
- [3] Chua, K.J., Chou, S.K., Yang, W.M. (2010). Advances in heat pump systems: A review. *Applied Energy*, 87: 3611-3624, doi: 10.1016/j.apenergy.2010.06.014.
- [4] Ostrowski, J., Anjos, M.F., Vannelli, A. (2012). Tight mixed integer linear programming formulations for the unit commitment problem. *IEEE Transactions on Power Systems*, 27(1): 39-46, doi: 10.1109/TPWRS.2011.2162008
- [5] Sanaye, S., Niroomand, B. (2009). Thermal-economic modeling and optimization of vertical ground-coupled heat pump. *Energy Conversion and Management*, 50: 1136-1147, doi: 10.1016/j.enconman.2008.11.014
- [6] Hasan, A., Vuolle, M., Sirén, K. (2008). Minimisation of life cycle cost of a detached house using combined simulation and optimization. *Building and Environment*, 43:2022-2034, doi: 10.1016/j.buildenv.2007.12.003
- [7] Djuric, N., Novakovic, V., Holst, J., Mitrovic, Z. (2007). Optimization of energy consumption in buildings with hydronic heating systems considering thermal comfort by use of computer-based tools. *Energy and Buildings*, 39: 471-477, doi: 10.1016/j.enbuild.2006.08.009
- [8] Baluja, S. (1995). An empirical comparison of seven iterative and evolutionary function optimization heuristics. *Carnegie Mellon University*. CMU-CS-95-193.
- [9] Lauster, M., Teichmann, J., Fuchs, M., Streblow, R., Müller, D. (2014). Low order thermal network models for dynamic simulations of buildings on city district scale. *Building and Environment*, 73: 223-231, doi: 10.1016/j.buildenv.2013.12.016
- [10] Huchtemann, K., Müller, D. (2009). Advanced simulation methods for heat pump systems. *Proceedings of the 7th International Modelica Conference, Como, Italy*, 43:798-803, doi: 10.3384/ecp09430043
- [11] Viskanta, R., Behnia, M., Karalis, A. (1977). Interferometric observations of the temperature structure in water cooled or heated from above. *Advances in Water Resources*, 1(2): 57-69, doi: 10.1016/0309-1708(77)90024-0
- [12] Harb, H., Schütz, T., Streblow, R., Müller, D. (2014). A multi-agent based approach for energy management in microgrids. *27<sup>th</sup> International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems*.
- [13] Baluja, S., Caruana, R. (1995). Removing the genetics from the standard genetic algorithm. *Carnegie Mellon University*. CMU-CS-95-141.
- [14] EN ISO 7730 (2005). European standard. Ergonomics of the thermal environment – Analytical determination and interpretation of the thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.
- [15] Grünert, T., Irnich, S. (2005) *Optimierung im Transport – Band I: Grundlagen*. Shaker Verlag
- [16] STAWAG (2014). StromSTA<sup>®</sup> Öko für Wärmepumpe.



## **The SYNERGY project: a holistic approach for assessing the energy, hygrothermal, fire and environmental performance of building elements.**

Dimitrios Bikas, Dimitris Aravantinos, Christina Giarma, Karolos-Nikolaos Kontoleon, Theodoros Theodosiou, Katerina Tsikaloudaki

Laboratory of Building Construction and building Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece

**Abstract:** *The paper presents the content and part of the results produced under the context of the SYNERGY research project, which focuses on the holistic study and development of building elements with advanced performance in the fields of energy, hygrothermal, fire and environmental performance. Although the above aspects may have been studied individually in the past, there is a lack of information on their combined assessment both at a national and an international basis. The analytical information that is derived through the detailed analyses of each stage is going to be exploited by the industrial project partners for the improvement of their products and services, and at the same time it will be communicated to the engineering world through the development of computational tools and catalogues, leading ultimately to numerous benefits for the national economy and the environment.*

**Key words,** *energy efficiency, linear thermal transmittance, hygrothermal performance*

### **Introduction**

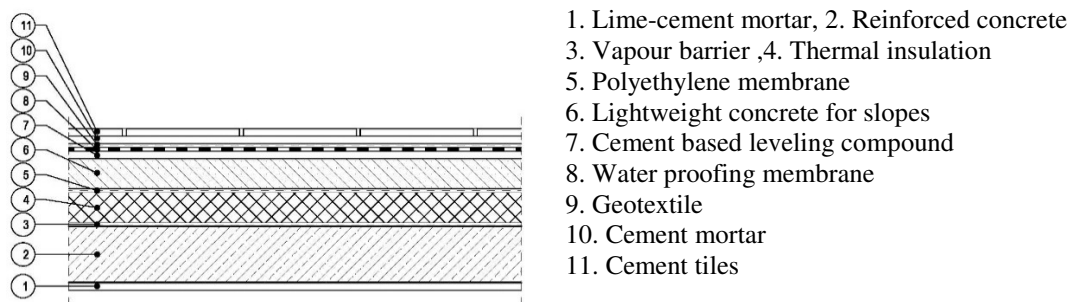
This paper presents steps of SYNERGY project that focuses on the research and the development of high energy-efficient building elements, assessed under integrated protection criteria and life cycle design aspects. More specifically, it concerns a holistic approach in designing and evaluating the building elements of new and existing constructions in Greece, with regard to their energy, hygrothermal, fire and environmental performances. It is elaborated by two academic units of the Aristotle University of Thessaloniki (the Laboratory of Building Construction and Physics and the Laboratory of Metal Structures) and two SMEs, FIBRAN, which plays a leading role as a producer of insulation materials both in Greece and in Europe, and TESSERA MULTIMEDIA, an ICT company that is active on the development of software and applications as well as on web design. During the project duration, a detailed analysis of all building elements met in the majority of constructions in Greece is conducted with reference to their energy, fire, hygrothermal, and environmental performances, as well as catalogues and computational tools for their properties' estimation are developed. Although the above aspects may have been studied individually in the past, there is still a lack of information regarding their combination at a national and international basis, which has led to the vulnerability of their proper practical implementation.

Such an approach is crucial for the development of efficient buildings in the view of the implementation of the forthcoming EPBD recast, which aims at the promotion of nearly zero

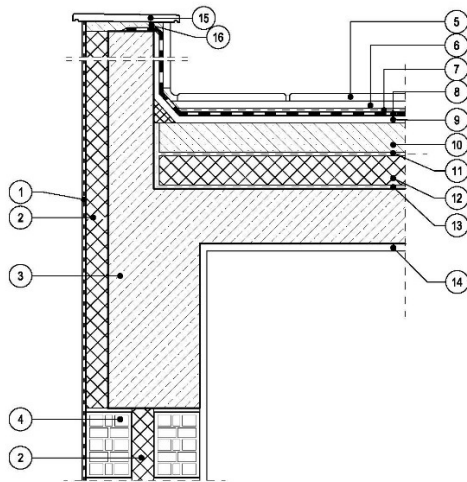
energy buildings and the enhancement of their sustainability characteristics during their entire life cycle. Apart from the knowledge and the theoretical results that will derive during the project, there are also more practical products, such as the catalogues and the computational tools with numerous constructional details and information regarding their thermophysical, hygrothermal, fire resistance and environmental properties. These tools are very useful for all engineers, especially during the design and the decision-making phases of a new building or a renovation project. In fact, their importance will come to light in a few years, when the design and the construction of a building will take into account several energy related criteria due to the near zero-energy building requirements.

### **The SYNERGY current and future outcomes**

Within the context of the SYNERGY project all the common construction element configurations that can be found in the building envelope of typical Greek buildings (load bearing elements, walls, roofs, floors) have been recorded, designed and systematically classified. The study refers to new, well-thermally insulated building as well as to existing buildings with poor or no insulation protection. Beyond the 180 construction details that have been produced for the individual building elements, details of their junctions have been elaborated, giving all necessary information for the appropriate layers' succession, the associated materials and the finishes. An example of the produced details is presented in Figure 1, representing the individual building component, i.e. a flat roof, and Figure 2, portraying the junction between a vertical and a horizontal building element, i.e. between the wall and the flat roof. The examined parameters and the methodologies that are used for the analysis are described below for each individual issue.



*Figure 1. Construction detail of a conventional flat roof.*



1. Lime-cement mortar
2. Thermal insulation for walls
3. Reinforced concrete
4. Brick masonry
5. Cement tiles
6. Cement mortar
7. Geotextile
8. Water proofing membrane
9. Cement based leveling compound
10. Lightweight concrete for slopes
11. Polyethylene membrane
12. Thermal insulation for roof
13. Vapour barrier
14. Reinforced concrete
15. Marble tile
16. Cement mortar

Figure 2. Construction detail of the junction between the vertical wall elements and the flat roof.

### The energy performance of the building elements

The energy performance of a building element is mainly represented by the value of its thermal transmittance (U-value). The U-value of each building element, that has been identified and included in the analysis, was calculated for different widths and thermophysical characteristics of the thermal insulation layer. For the remaining layers, the conventional widths and materials used in Greek constructions were taken into account. Given that among the objectives of the current project is to deliver catalogues and tools for engineers, a practical table was formulated for each building element, presenting the building element assembly along with the layers' configuration and a matrix presenting the thermal transmittance values that are derived for the different widths and thermal conductivity values of thermal insulation (Figure 3). The width of thermal insulation varies from 0.0m, to 0.14m with a step of 0.01m. For the thermal conductivity, typical values of the insulation materials that are available in the Greek market were taken into account. The combinations of  $d$  and  $\lambda$  that result in U-values lower than the maximum allowed values per climatic zone are indicated in the matrix with different color. The practical merit of this matrix is that the engineer can make a quick estimate of the required thermal insulation, while at the same time the accurate and comprehensive construction detail is at hand.

BUILDING ELEMENT		$\Delta\alpha-130B$	
Flat roof with thermal insulation above the concrete slab with no air gap			

Figure 3. A practical table for estimating the thermal transmittance of a particular building element for different widths and thermal conductivity values of the thermal insulation material.

Beyond the thermal transmittance, another significant parameter for the evaluation of the overall thermal behaviour of the building envelope is the estimation of the linear thermal transmittance coefficient  $\Psi$  of the thermal bridges located in composite building elements and at the intersection between the construction elements. Values of  $\Psi$  included in the national atlas published by the Technical Chamber of Greece or ISO 14863, neglect the influence of the material thickness and thermal properties on  $\Psi$ . This information is of great importance in cases where, beyond the fulfilment of regulation requirements, a more accurate estimation of the building's actual heating and cooling needs is required.

Within the context of the SYNERGY project,  $\Psi$  values have been calculated, resulting in a prolonged atlas for thermal bridges which present for different widths of thermal insulation, all possible positions of the thermal insulation layers and different finishes of the vertical building elements. For every examined case, apart from the calculation  $\Psi$ , the temperature profile within the construction element is calculated and presented on the elements' cross-section. This representation has a twofold merit: it assists non-specialists to understand the thermal bridging effect and it constitutes valuable information when estimating the probability of vapour condensation. The calculations were conducted with the help of a 2-D finite element software and in line with ISO 10211. The presentation of the results for each building element follows the example of Figure 4.

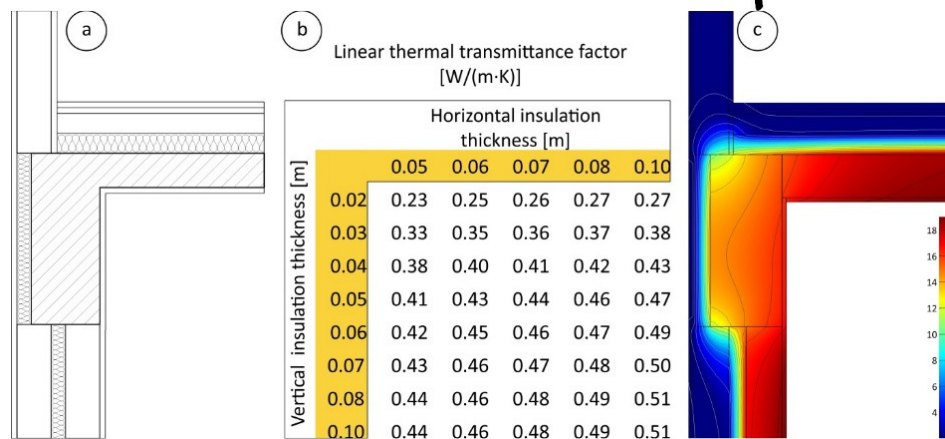


Figure 4. The temperature distribution at the junction of a flat roof and a vertical wall element and the resulting values of linear thermal transmittance  $\Psi$  for various widths of thermal insulation.

### The hygrothermal performance of the building elements

The study of the hygrothermal behaviour of the building elements reflects their performance against the presence, accumulation and variation of moisture in their mass or on their surface, as these phenomena are induced by various factors. More specifically, two main axes can be discerned: first the estimation of vapour condensation risk inside and on the surface of the building elements, as well as their performance against rain and driving rain.

For the estimation of vapor condensation risk a calculation tool has been developed. It can be used for the determination of the temperature and the vapour pressure profiles prevailing across the building element, as well as the risk of interstitial condensation. If the latter occurs, the amount of the condensation is calculated, along with the amount of evaporation. The comparison between the condensation and evaporation rates follows, which indicates whether moisture is accumulated in the building element on an annual basis. The algorithm employed by the tool is in line with the international standards [2-3]. The basic steps are summarized as follows:

- Selection of the boundary conditions for the building element analysis (i.e. city, for the climatic data, and usage density, for the vapour production).
- Determination of the building element's position and composing layers, as well as the materials of each layer. The tool is equipped with a database containing the common building elements and materials, which can be enriched with new assemblies.
- Calculation of the saturation vapour pressure and the water vapour pressure for the assessment of the interstitial condensation phenomenon on a monthly basis.

If interstitial condensation occurs, the first month of the condensation is determined. The accumulated condensate is calculated till the rate of condensation becomes negative, i.e. till evaporation occurs.

### The fire resistance performance of the building elements

The study concerns the fire dynamics of building enclosures, i.e. the detailed analysis of the fire performance of common building elements adopted in the majority of constructions in the Greek district. It is critical to point out that the propagation and spread of fire from one space to another is a highly complicated and multifaceted phenomenon. Evidently, the prediction



processes to quantify the behavior of fire and to extort the means to reduce the impact of fire on people, property, and the environment is extremely valuable. In order to undertake the above study FDS is applied; Fire Dynamics Simulator (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow developed by the National Institute of Standards and Technology (NIST). The above software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires. The exploitation of CFD and FEM research models is important in order to predict precisely the actual fire scenario, determine accurately the time-history temperatures at each discrete point (evolution of temperature profiles  $T(t)$ ) and override the need of large-scale fire experiments.

The present study concerns a typical building volume which consists of two adjoined and similar indoor spaces (Figure 5). The investigated indoor spaces are separated by an interior wall and a corridor permits their connection by means of the inside doors facing the corridor. The other two walls of both interior spaces split the indoor environment from the outdoor environment. The structure of the involved opaque surfaces that form the building enclosure vary within a wide range of possible solutions that take into account the category of structural members, the type of the insulation material, the thickness and position of insulation, and the type and thickness of the assumed coatings. Aiming to acquire a broad range of outcomes the transient problem is carried out for three typical fire scenarios, which cover a representative width of possible fire incidents. The extracted outcomes are important in order to reduce the fire risk of buildings that describe the construction practices in Greece. In conclusion, recommendations for the determination of the efficient use of fire insulation materials and the benefits that can be obtained in comparison to non-insulated structural elements will be specified.

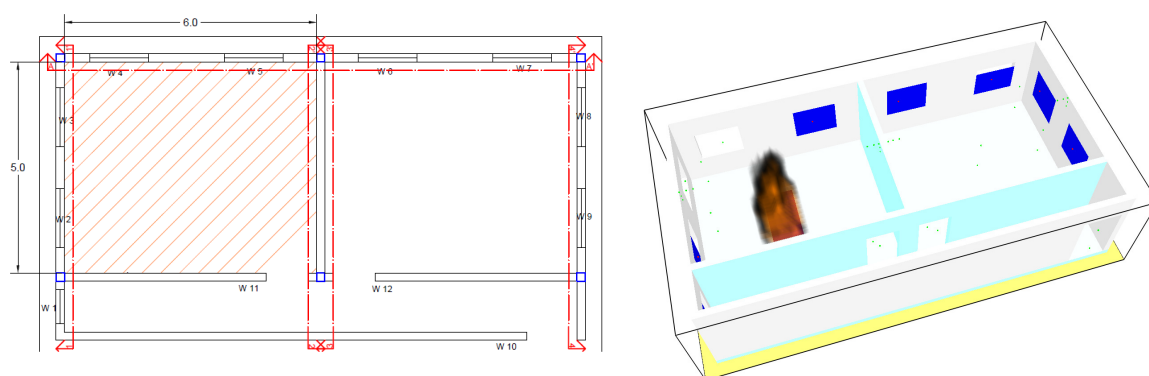


Figure 5. (left) Plan view of the investigated building enclosure; (right) transient analysis of an assumed fire scenario via FDS.

### The environmental performance of the building elements

Under this task the aim is to study and estimate the environmental impact in the different levels of building materials, elements and whole buildings, according to life cycle principles, with the use of LCA tools. The intention is to show clear results and provide useful practical information of the environmental performance of the building materials, elements and whole buildings to engineers and to construction industry professionals.

In accordance with the principles of sustainable construction, the minimization and reduction of the impacts on nature and environment depends on the performance of the building during all the phases of its life. It is well known that the life-cycle of a building is a process, which starts with the formulation of a need to build and the preliminary planning. The phase of construction itself covers a rather short period, in contrast to the use and reuse of various building elements and buildings as wholes, eventually ending in the demolition of the building and waste management, or deconstruction and reuse of building elements. During every phase of the life cycle, decisions are made concerning the performance of the building, with or without consideration of the full potential impacts of these decisions. The LCA is a technique that evaluates the inputs and outputs of raw material and emissions in each step of the material life, adding the resource extraction impact and the emission of pollutants. Its origin is the immediate products industry and it was adapted to the environmental evaluations of building. The application, assembly form and use of equipment in the building system modify its environmental performance. It is worth noting that the absence of database of materials of the Greek market makes the use of LCA software, created in other countries, difficult because these are supplied by local databases or similar. Considering this difficulty, it is very important to transform the results of an LCA in data understandable to architects and engineers responsible for the selection of building materials, elements and systems. At the beginning of any decision, before setting their own priorities, architects and engineers need to be aware of the great variety of issues that should be re-evaluated from the perspectives of life-cycle and environmental sustainability. LCA is very important to compare possible alternative solutions, which can bring about the same required performance. The facility of using the system and understanding of the results are considered crucial in the use of the life-cycle principles for selecting building systems.

## **Conclutions**

The need for energy conservation in buildings is an urgent priority both for Europe and at a national level. The requirements of current regulations and the more stringent requirements specified in the foreseeable future (EPBD recast, EUROCODES 2 and 3, EPD-Environmental Product Declarations) necessitate the thorough analysis and development of reliable component solutions that will ensure high energy and hygrothermal performance, fire safety and minimized environmental impacts in the lifecycle of the building components and buildings. The project not only focuses on the development and organization of theoretical knowledge, but also aims at the wide dissemination of its results, mainly through the development of user-friendly databases and calculation tools for the basic axes of the study. The unified tool that incorporates all the results obtained from the estimation of thermophysical, hygrothermal, fire and environmental performance of building elements with respect to their constructional configuration and the climatic conditions is web-based in order to facilitate its distribution and use by multiple users.

It is important to highlight that the expected products of the SYNERGY project will not only act as a guideline for the technical community, but it will promote the use of building



materials, which are efficient from every aspect of view. Subsequently, the private companies that participate in the project will not only benefit from the transfer of knowledge, but will also support their products, as well as gain important information for their further development. Within this context, the SYNERGY project can lead to significant energy savings and reductions in greenhouse gas emissions through the implementation of its results.

## References

- [1] *EN ISO 6946, 2007 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method.*
- [2] *ISO 13788, 2012 Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods*
- [3] *ISO 10456, 2007. Building materials and products - Hygrothermal properties - Tabulated design values and procedures for determining declared and design thermal values.*
- [4] Hall C., Green K., Hoff W. D., Wilson M. A. (1996), "A sharp wet front analysis of capillary absorption into n-layer composite",. *Journal of Physics D: Applied Physics*, 29, pp. 2947–2950.
- [5] Hall C., Wilson M. A., Hoff W. D. (1995), "Water Movement in Porous Building Materials – XIII. Absorption into a two-layer composite", *Building and Environment*, 30, 2, pp. 209-219.
- [6] Janssen H, Derluyn H, Carmeliet J. (2012), "Moisture transfer through mortar joints: a sharp-front analysis", *Cement and Concrete Research*, 42, pp. 1105–1112.
- [7] Blocken B., Carmeliet J. (2012), "A simplified numerical model for rainwater runoff on building facades: possibilities and limitations" *Building and Environment*, 53, pp. 59-73.



## QUALITY CONTROL MECHANISMS IN BUILDING PRODUCTION MANAGEMENT IN NIGERIA

BUSTANISHEHU.A.<sup>1</sup>, OYEMOGUM IJEGO.M.<sup>2</sup>

<sup>1</sup>spinal engineering services limited, garki ii abuja, nigeria.

<sup>2</sup> department of building, faculty of environmental sciences, university of jos, p.m.b. 2084, jos. Nigeria

### ABSTRACT

*This work focuses on the depreciating quality of buildings produced with particular attention to their production process. It highlights the need to ensure adequate knowledge of quality control mechanisms in the production of buildings in order to meet the expectation of the public. The work also highlights the concept of quality assurance and control as they apply to the construction of buildings. The investigation carried out shows that the professionals in the Nigerian Construction Industry are still limited in awareness of quality control mechanisms in building production management this translates to their low involvement in quality control measures in the production process. Some of the professionals rarely carry out on the spot inspection of ongoing projects to guide those contractors who lack knowledge of necessary tests and standards required. Some major factors affecting quality control in the building production process are better craftsmanship, testing and or measurement of work and products, education and training and improved management – employee relationship.*

**Key Words:** *Building production process, Quality Assurance, Quality Control*

### INTRODUCTION

Quality control in building production process deals with the complete implementation of quality policies by assuring control measures are strictly adhered to throughout the production process. Quality sustenance in the Nigerian construction industry is a major problem with regard to design and construction management. A high construction defects rate has greatly affected the reliance of the public on housing purchase. This makes it necessary to develop a quality control mechanism for reducing building defects. [1] opines that quality control entails testing of products to uncover defects and reporting to management to allow or deny product use.



The research aims at evaluating the knowledge of quality control mechanisms available in building production management for sustainable productivity in the Nigerian Construction industry.

The primary objectives of the study are:

1. To identify the mechanisms of quality control
2. To assess the efficacy of the current quality control processes in the Nigerian construction industry
3. To make recommendation for effective quality control mechanisms where not available for sustainable building production management.

[2] opines that the building production process consists of five distinct but not mutually exclusive activities namely: Construction planning, Buildability (i.e. the optimum use of construction knowledge) and Maintainability analysis, Quality control, Assembly and Incidentals. During construction planning, it is safe to assume that the production information documents must be properly approved for execution for effective planning to take place. Construction planning is thus concerned with economic building rather than cheap building. Clients therefore require the efficient utilization of resources and governments express their minimum demands in the form of building regulations, codes and laws.

The basic function of Buildability and maintainability analysis is to determine and minimize or remove waste and wasted efforts prior to commencement of work on site. This analysis is not meant for the builder to find faults in the designer's work but to study the production information and suggest ways in which the design could be improved upon. The most important job of the builder is to complement the efforts of the designer and add more value to the client's investment.

Quality Control issues are vital for the builder to build right the first time.[2] clearly states that understanding the design and requirements of a project are important for successful quality control of a project. Where there are changes to the original design/specification, they should not compromise the quality of the work.

The Nigerian government in a bid to assure quality control in the construction industry has over the years promulgated and enacted various decrees and acts to assist in regulating various professionals in the construction industry. Some of the decrees and acts in existence in the Nigerian construction industry are:

1. Cap 55 of 1970 amended by decree 27 of 1992 establishing the Council for the Regulation of Engineers (COREN).
2. Act Cap B 13 LFN 2004 (formerly Decree 45 of 1989) established the Council of Registered Builders of Nigeria (CORBON).
3. Decree 3 of 1988 established Town Planning Registration Council of Nigeria (TOPREC).



4. Decree 22 of 1986 established the Quantity Surveyors Registration Council of Nigeria (QSRCN).
5. Decree 44 of 1978 established the Surveyor's Registration Council of Nigeria (SURCON).
6. Cap 111 of the Federal Republic of Nigeria (formerly decree 24 of 1975) established the Estate Surveyor's and Valuer's regulation Board of Nigeria (ESVRBN).

The essence of these legislations is to ensure adequate quality control in construction projects for the various professionals. Desired project standards can therefore be achieved through the provision regulations and policies. The construction standards throughout the country have however remained at a low standard when compared with standards of the international community [3].

[4]state that there are three reasons why management decisions affect the quality of construction namely:

1. Lack of Management Commitment: Some of the reasons which account for lack of management commitment is lack of awareness of the benefits of management quality control and haphazard implementation due to market pressure.
2. Inconclusive Interpretation of Required Standard:[4] opine that some ambiguity may arise with reference to the use of the ISO standards as these have their origins in the engineering sector.
3. Inadequate training policies: Most indigenous construction companies do not seem to have a training policy on ground as most of the workers are employed on ad-hoc bases.

## METHODOLOGY:

The methodology applied in the research was the literature review, semi-structured interviews and questionnaire survey. The target population for the research was professionals in the industry (Architects, Builders, Quantity Surveyors, Town planners, Land Surveyors and Estate Valuers.) For the data analysis, Simple percentage method and ranking methods were employed.

## RESULTS AND DISCUSSION:

*Table 1: Professionals with quality control policies in their organisations.*

Quality Control Policy	No of Responses	% of Responses
Yes	34	72
No	13	28
Total	47	100

A total of 47 respondents were achieved for the research and in order to guide the respondents on the focus of the study a question was asked on the meaning of quality. Table 1 shows the responses.

The result from table 1 shows that 72% of respondents have quality control policies in their companies while 28% have no quality control policies.

Table 2: Quality control systems used to drive policy in the industry

S/No	Standards	No. of Respondents	% of Respondents
1	ISO 9001 – 2000 (Quality Management Principles)	10	29
2	BS 5750 (Quality Assurance Systems)	7	20
3	EN 29002	5	15
4	ISO 14000	4	12
5	ISO 14001 – 2004	3	9
6	National Building Code 2006	5	15

Table 2 indicates that the National building code and EN 29002 are most widely used to ensure quality control with 15% of respondents each using it.

Table 3: Measure/Indicator of quality in the Nigerian construction industry

S/No	Measure /Indicator	No of Respondents	% of Respondents
1	Customer Satisfaction	4	8
2	Management commitment	9	19
3	Repeat business	4	8
4	Regular inspection	5	11
5	Skilled Labour	4	8
6	Training	6	13
7	Period of warranty	3	6
8	Keeping to construction standards	4	8
9	Certified quality programs in place	5	11
10	Appearance of completed project	3	6

Table 3 shows 19% of respondents believe management commitment to quality is the best indicator of quality control while the period of warranty indicated on the product is the least indicator of quality.

Table 4: Control mechanisms used in Building Production Management

Mechanisms	Very High	High	Ave.	Low	Very Low	Rank Sum	Rel. Index	%	Rank Order
Organisational culture	7	9	9	14	8	148	0.63	63.00	9th
Management commitment	5	8	9	11	14	162	0.68	68.00	8th
Skilled work force	2	5	11	17	12	173	0.74	74.00	3rd
Effective communication between management and employees	2	5	9	18	13	176	0.75	75.00	2nd

<i>Training and Education</i>	5	8	3	13	18	172	0.73	73.00	4 <sup>th</sup>
<i>Well defined job roles and responsibilities</i>	5	6	7	17	12	166	0.71	71.00	5 <sup>th</sup>
<i>Clear project goals and objectives</i>	2	5	8	14	18	182	0.78	78.00	1 <sup>st</sup>
<i>Regular performance reviews</i>	5	7	5	21	9	163	0.69	0.69	7 <sup>th</sup>
<i>Existing quality control policy</i>	6	5	12	7	17	165	0.70	70.00	6 <sup>th</sup>

From table 4, clearly defined company goals and objectives ranked first in the quality control mechanisms used in building production management with a relative index of 0.78. Next was effective communication between employers and employees with a relative index of 0.75. The least quality control mechanism was organizational culture with an index of 0.63.

Table 5: Professional's Ranking of the Important Elements of Quality Control

<i>Elements</i>	<i>Very High</i>	<i>High</i>	<i>Ave.</i>	<i>Low</i>	<i>Very Low</i>	<i>Rank Sum</i>	<i>Rel. Index</i>	<i>%</i>	<i>Rank Order</i>
<i>Training and education of employee and management staff</i>	2	6	10	12	17	177	0.75	75.00	2 <sup>nd</sup>
<i>Clearly defined guidelines for client satisfaction</i>	5	8	6	16	12	163	0.69	69.00	5 <sup>th</sup>
<i>Means and methods for ensuring continuous improvements</i>	5	8	4	18	12	165	0.70	70.00	4 <sup>th</sup>
<i>Clearly defined goals relating to quality work performance</i>	5	3	6	13	20	181	0.77	77.00	1 <sup>st</sup>
<i>Systems for collecting and tracking data for ensuring quality objectives</i>	5	9	7	16	10	158	0.67	67.00	6 <sup>th</sup>
<i>Review process to identify errors in the system</i>	7	2	10	12	16	169	0.72	72.00	3 <sup>rd</sup>

Table 5 shows that the most important element/characteristic of quality control is having clearly defined goals relating to work performance with a relative index of 0.77. Next is training and education of staff with a relative index of 0.75 and the least important element was the system for collecting and tracking data for ensuring quality. This had an index of 0.67.

Table 6: Suitable Steps for Implementing Quality Control Systems in the Nigerian Construction Industry

Steps	Very High	High	Ave.	Low	Very Low	Rank Sum	Rel. Index	%	Rank Order
Securing Client's commitment to quality	3	5	8	14	17	178	0.77	77.00	1 <sup>st</sup>
Educate and change the attitude of staff	2	5	10	17	13	175	0.75	75.00	3 <sup>rd</sup>
Prepare quality plans for all levels of work	3	6	7	15	16	176	0.76	76.00	2 <sup>nd</sup>
Promoting staff participation and contributions through quality control motivation programmes	3	5	8	14	17	178	0.77	77.00	1 <sup>st</sup>
Regular review of quality plans and performance measurements	6	2	8	17	14	172	0.73	73.00	4 <sup>th</sup>

On the steps for implementing quality control, table 6 shows commitment of the client to quality and staff participation in motivation programs were most important with a relative index of 0.77 each. Next ranked preparation of quality plans for all levels of work with an index of 0.76 and least was review of plans and performance measurement with an index of 0.73.

Table 7: Processes to Minimize Actual or Potential Non-Conformance to Quality Standards

Processes	Very High	High	Ave.	Low	Very Low	Rank Sum	Rel. Index	%	Rank Order
Identify potential non-conformance risks to quality control	2	7	6	8	10	116	0.70	70.00	4 <sup>th</sup>
Initiate Regular quality report	3	1	7	13	9	123	0.75	75.00	3 <sup>rd</sup>
Notification of non-conformance	4	3	5	6	12	109	0.66	66.00	5 <sup>th</sup>
Taking necessary actions against non-conformance issues	1	3	5	13	11	129	0.78	78.00	2 <sup>nd</sup>
Proper analysis of non-conformance reports	5	4	10	9	5	104	0.63	63.00	6 <sup>th</sup>
Regular quality tracking on projects	3	2	5	7	16	130	0.79	79.00	1 <sup>st</sup>

On processes to minimize actual or potential non-conformance to quality standards, table 7 shows that tracking report of work is most important with an index of 0.79. Next is attempting to resolve any non-conformance issues with an index of 0.78. The least important process was the distribution of non-conformance reports with an index of 0.63.

Table 8: Barriers to Quality Control in the Building Production Process

<i>Barriers</i>	<i>Very High</i>	<i>High</i>	<i>Ave.</i>	<i>Low</i>	<i>Very Low</i>	<i>Rank Sum</i>	<i>Rel. Index</i>	<i>%</i>	<i>Rank Order</i>
<i>Lack of skilled labour</i>	7	6	10	9	15	160	0.68	68.00	1 <sup>st</sup>
<i>Award of contract to lowest bidder</i>	7	7	19	4	10	144	0.61	61.00	3 <sup>rd</sup>
<i>Lack of effective building teams skills</i>	7	8	9	16	7	149	0.63	63.00	2 <sup>nd</sup>
<i>Use of adversarial forms of contract</i>	6	14	10	11	6	138	0.59	59.00	4 <sup>th</sup>
<i>Hostile union environments</i>	12	7	14	8	6	130	0.55	55.00	6 <sup>th</sup>
<i>Too many restrictive building codes</i>	8	15	10	5	9	133	0.57	57.00	5 <sup>th</sup>
<i>Contractor reliance on litigation process for dispute resolution</i>	8	18	8	7	6	126	0.54	54.00	7 <sup>th</sup>

Table 8 shows the greatest barrier to quality control in the building production management process is Lack of skilled workers with a relative index of 0.68. The next barrier is the lack of effective teams with an index of 0.63 while the least barrier was reliance on litigation process for dispute resolution with an index of 0.54.

*Table 9: Drivers of Quality Control in the Building Production Process*

<i>Drivers</i>	<i>Very High</i>	<i>High</i>	<i>Ave.</i>	<i>Low</i>	<i>Very Low</i>	<i>Rank Sum</i>	<i>Rel. Index</i>	<i>%</i>	<i>Rank Order</i>
<i>Education and Training</i>	6	3	7	14	17	174	0.74	74.00	3 <sup>rd</sup>
<i>Testing and measurement of work done</i>	2	6	7	13	19	182	0.77	77.00	2 <sup>nd</sup>
<i>Improved craftsmanship</i>	2	4	9	14	18	183	0.78	78.00	1 <sup>st</sup>
<i>Improved employee-management relationship</i>	5	4	9	11	18	174	0.74	74.00	3 <sup>rd</sup>
<i>Stronger prequalification criteria</i>	4	11	10	8	14	158	0.67	67.00	5 <sup>th</sup>
<i>Increase in adoption of design and build contract</i>	2	12	13	5	15	160	0.68	68.00	4 <sup>th</sup>

Table 9 shows that improved craftsmanship and on the spot testing of products and materials are the greatest drivers of quality in the building production management process with indexes of 0.78 and 0.77 respectively. The least driver was improving pre-qualification criteria for contractors.





## CONCLUSION

The complexity of the building process demands a high level of awareness and commitment to quality control standards. Poor quality implies wasted resources and low standards in finished products. Quality in the building production process ensures client satisfaction, consistency in conforming to specifications and achieving the overall project goals. Quality control and assurance are however the sole responsibility of the contractor and the research shows that those responsible for quality in the building production process in the Nigerian Construction Industry have failed in their duties.

The assessment of quality control practices is very low as majority of the contractors do not carry out material tests to ascertain their quality before incorporating them into the projects. Some consultants also fail in their responsibility to carry out on the spot checks to guide contractors who lack knowledge of the specific tests and standards required. There should therefore be a qualified registered professional resident on site to manage the quality control mechanisms for building projects. This research recommends that in order to meet the desired quality control goals in the building production process, there is a need for the training of construction industry employees on proper and adequate quality control measures to be used during the building production process.

## REFERENCES

- [1] Yung, W.K.C., (1997) The Value of TQM in the Revised ISO 9000 Quality System.
- [2] Bamisile, A. (2004) Building Production Management Services (The Unique Role of Builders). A paper presented at the annual conference of Ife University Association of Building Students. ObafemiAwolowo University, Ile-Ife.
- [3] Ezeokonkwo, J.U., Ezemerihe, A., Obiegbo, M.E., Akabogu, S., (2002)Effective Building Procurement and Delivery in Nigerian Construction Industry. Nimo, Anambra State.Rex Charles & Patrick Limited.
- [4] Obiegbo, M.E., (2003) Building Development Process – A Search for Cohesiveness and Teamwork. A paper presented at the reception ceremony of the 13<sup>th</sup> NIOB President by the Anambra State Chapter. November 2003.

## New Generation of Curtain Walls

Tywoniak, Jan<sup>1</sup>; Bureš, Michal<sup>1</sup>; Lupíšek, Antonín<sup>1</sup>; Volf, Martin<sup>1</sup>

<sup>1</sup> Czech Technical University in Prague, Czech Republic

**Abstract:** *The first part of this paper describes how a façade of a 40 years old campus building in Prague has been replaced. This replacement served as an impulse for a) a discussion about energy performance of a whole building, b) our own development work. As the replacement used quite high-quality curtain wall elements, the resulting situation in terms of energy performance of the building is quite different: the transmission heat losses have been minimized. The ventilation strategy has become a key factor in both the energy use and indoor environment quality. Given the low g-value of the high-quality glazing and efficient shading system, solar gains are not significant compared to internal heat gains. All these aspects should be considered advantageously when creating overall new energy solutions and setting targets for the building design.*

*The second part of this paper presents the development of the curtain wall element (panel) itself with a special focus on the environment. Renewable materials replacing aluminum and oil-based products with wood or wooden products are used to the highest possible extent together with active renewable energy components (photovoltaics). The paper contains material solutions, thermal analysis and environmental assessment of the newly developed products, and the lessons learned from prototyping.*

**Keywords:** *curtain wall, building retrofit, energy saving, wood materials, life cycle approach*

### 1. Introduction

Since 1960's, a significant share of facades on non-residential buildings has used light-weight curtain walls [1], differentiated between element (ready made panels) and stud/transverse beam structural principles. In the past, such solutions were characterized by a high energy-demand in terms of space heating. Moreover, the curtain walls with their large glazed areas and low thermal inertia have contributed to overheating the buildings and/or led to a significant cooling energy demand. Structural elements (main frame, mullions etc.) are usually made of aluminum or steel. Significant thermal bridges were usually present. In the recent years some studies concerning environmental profile of used products and life cycle analysis were published. Presence of asbestos fibers in the boards used in curtain wall was recognized as a further key-problem to be solved during building retrofit. This modern way of building allowing (questionable in some cases) very large glazed areas of the facades should be considered differently in term of life cycle approach: The time for exchange of a building component (life cycle period) which is about 30 years for windows in traditional facades is now valid for whole building envelope.

Many of the curtain walls from 1960's have already been replaced, however, many of them remain more or less in their original state, including more than 300 school buildings solely in the Czech Republic. Other countries in Central Europe appear to be in the same situation.

Several technologies for refurbishment of such buildings can be observed in practice: a) total replacement of existing curtain wall with new one, b) partial replacement: principal frame

remains, new structural elements are added together with filling, cladding and windows, c) total replacement by traditional aerated concrete wall accompanied with external thermal insulation composite system (ETICS) and windows. The choice of technology is influenced by overall architectural solution, total size of the building, by the investment costs, by the accessibility of the site, time available for building retrofit and other arguments (tradition, skills of contractor etc.). In generally, an advanced, industrialized way of assembly shall be preferred for new and more efficient generation of building envelopes.

## **2. Real case study**

One example is a 40 years old campus building in Prague that was refurbished during 2013 (Fig. 1). The old curtain wall with very poor performance [2] was completely removed and replaced by a new element façade [3] of a significantly higher quality which meets today's recommendations in matter of energy efficiency. In advance completed panels of size 3 m (width) x 3,6 m (high) were installed there.

### **2.1. Building description**

This tall building (Fig. 1) has a form of a simple cuboid with 15 floors and was finished in 1971. It was constructed using a curtain wall corresponding to existing requirements and the state of the technology. Probably due to high investment costs, the originally planned mechanical cooling of the building was not installed. The offices are oriented mainly to the SW façade. Seminar and meeting rooms are situated predominantly on the opposite side (NE). Ever since the building has been in use, problems with overheating and high energy consumption have been reported. Old elements were completely removed. New elements differ in size (double width) and in overall quality (Tab. 1). The new façade uses more appropriate size and type of window openings (Fig. 1). Motor-operated and locally/centrally controlled venetian blinds are integrated into the SW elements.

### **2.2. Technical data and energy performance discussions**

Tab. 1 compares main technical data of the original and new elements, respectively. Generally, the fundamental change in the quality of the building envelope implies necessary changes in the heating and ventilation of the building otherwise the optimum and indoor quality cannot be reached. Tab. 2 presents the results of an indicative calculation of heat losses and heat gains for the selected floor of the building during the heating season. It is evident that even at very cold external air temperatures, internal heat gains (metabolic heat and office equipment) in daytime are significant. By exploiting of waste heat from local server unit (10 kW) "the zero-energy level" can be theoretically reached by winter design temperature (-13 °C). Naturally, this would require an advanced technical system with intelligent control.

### **3. Light-weight curtain wall made of wooden based panels**

#### **3.1. Description**

Inspired by the retrofit of the campus building described above, an alternative system solution using a light-weight curtain wall of a panel type (Fig. 2) has been designed [4]. The solution should primarily replace the obsolete type of curtain walling, but it can also be applied to new constructions. Main structural materials (panel supporting frame, exterior and interior design boards) and supplementary materials (thermal insulation and façade cladding, window frames and sash) of the proposed wall system are made of wood-based materials.

The panel can be used with different additional components. An opaque part can have the form of a ventilated façade equipped with active renewable energy components (photovoltaic, solar heat collectors), supporting grid for greenery purposes or traditional cladding materials (glass, wood, fiber-cement, etc.). Units for de-centralized mechanical ventilation with heat recovery, motor controlled external blinds and other devices can be used as well to improve the overall energy balance of the building.

Typically, the basic module (panel) is extended with an additional wall with a cavity on the interior side. The piping (electrical wiring, weak current systems, heating distribution) or heating bodies can be installed here. Furthermore, it can contain control elements of the blinds, heating, cooling and ventilation.

#### **3.2. Thermal analysis**

The technical solution meets a higher level of current requirements on thermal protection of buildings in the Czech Republic. Depending on the type of the thermal insulation material, this construction reaches thermal transmittance values ranging from 0,22 to 0,19 W/(m<sup>2</sup>K). The quality of the thermal insulation can be further improved by using new generation materials (vacuum insulation panels, aerogels) which represent an advantage, as they can be placed into the protected position already in the factory without the risk of being damaged during the construction process. The curtain walls are fitted with high performing wooden windows. The technical solution of the casement allows the window to be fitted without the frame being visible from the exterior. Triple glazing thermal transmittance ranges from 0.70 to 0.54 W/(m<sup>2</sup>K). These properties help decrease the thermal loss through the building envelope by 70 % in comparison to the old type of the curtain wall. Annual energy demand for heating and related costs of heating can be decreased by more than 50 % by changing solely the building envelope.

#### **3.3. Environmental assessment**

Replacing the aluminum and oil-based products by wood or wooden products is the first step in the process of creating an environmentally efficient design. Specifically, the design used laminated veneer lumber, oriented strand board, cork and wood-fiber insulation, fiber board, etc. (see Fig. 2). This curtain wall contains 93 % by weight of wood-based materials in its opaque variant and 65 % by weight in its transparent variant. Fig. 4 compares the mass

distribution of the materials in the wood-based curtain wall (design in question) and in the standard aluminum curtain wall.

The next step consisted of an environmental assessment of the panel through a simplified analysis of the life-cycle assessment (LCA). The wood-based panel has been compared with other two alternatives for retrofitting a building: a) light-weight curtain wall made of aluminum-based panels, b) aerated concrete masonry with ETICS with expanded polystyrene (Tab. 4).

#### 4. Concluding remarks, future work

We have shown that curtain walls meeting today's legislative requirements and recommendations can result in a basically different energy performance. Ventilation strategy seems to be more important than the heat transmission (already significantly reduced), as far as indoor comfort and energy demand are concerned, especially in case of highly occupied buildings (schools, office buildings). Passive solar gains are no longer important as an energy source. In the campus building described in this paper, additional installation of a ventilation system with heat recovery is under preparation now.

The designed curtain wall system described in the second part of the paper will be further tested [4]. The test will focus on thermal transmittance and thermal inertia, humidity and moisture related problems and the technology of assembling. Development should continue in order to reach high flexibility in sizing, to improve external design and to integrate additional features.



*Figure 1 left: original curtain wall during disassembly (March 2013), right: new curtain wall (July 2013). Noticeable are both, indoor and outdoor venetian blinds and different window openings.*

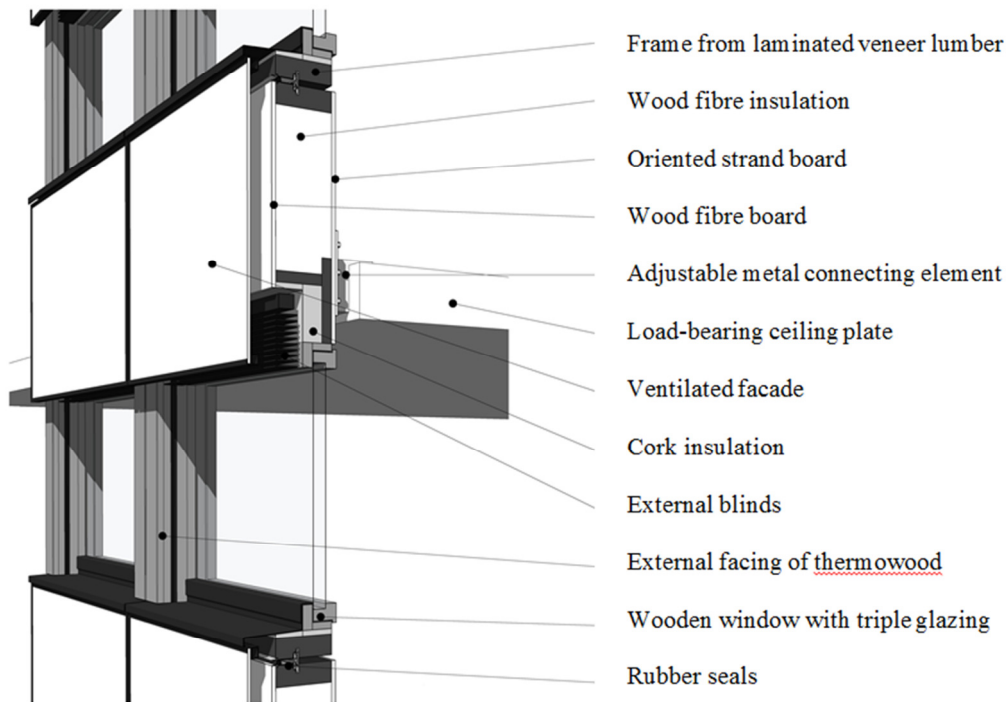


Table 1 Main data on original and new curtain wall

Original curtain wall		
	Short characteristics	Thermal transmittance [W/(m <sup>2</sup> K)]
Opaque part (42 %)	Polystyrene 60 mm	0,6
Transparent part (58 %)	Double glazed in metal frames	4,0
	Estimation with significant thermal bridges	Mean value: $U_{\text{mean}}$ 3,0
Shading	Blinds alternatively placed from the interior side or between glazing panes, sun protective foil placed at interior surface additionally	
New solution		
Opaque part	Mineral wool 140 mm,	0,19
SW: 48 %, NE: 37 %	extruded polystyrene 50 mm	
Transparent part	Triple glazing, insulating edge	SW: $U_g$ 0,5 NE: $U_g$ 0,6
SW: 52 %, NE: 63 %		Mean value SW: $U_{\text{mean}}$ 0,68 NE: $U_{\text{mean}}$ 0,87
Shading	SW: integrated venetian blinds, motor controlled + movable indoor blinds	

Table 2 Simplified estimation of specific heat losses for one floor, comparison original and new solution

	Original	New	Diff. [%]
Specific transmission heat loss $H_T$ [W/K]	1364	360	- 74
Specific ventilation heat loss $H_V$ [W/K] by full occupancy (120 person, ventilation 25 m <sup>3</sup> /h.Pers)	550	550	0
Total specific heat loss $H$ [W/K]	1914	910	- 53
Heating load at winter design temperature (-13 °C) [kW]	65,1	30,9	- 53
Estimated heat gains by persons and office equipment [kW]	14	14	0
Server unit		(10)	(+71)



*Figure 2 Scheme of curtain wall from wood based panels*



*Figure 3 left: the prototype during assembly - notice the cork insulation, right: view of the completed prototype in the test wall at University Centre for Energy Efficient Buildings (UCEEB)*

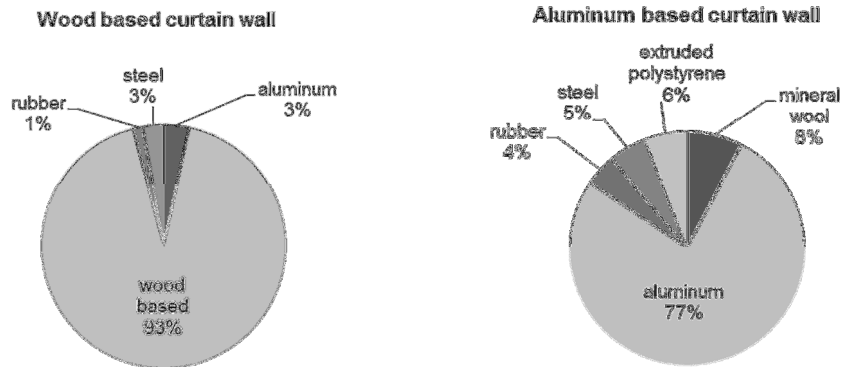


Figure 4 Mass distribution of the materials in the wooden based and an aluminum curtain wall (an opaque variant) with dimensions 3,3 (h) x 1,5 (w) meters.

Table 4 Comparison of the two main environmental indicators

	Wooden based panel	Aluminum based panel	Masonry with ETICS
Embodied energy, <i>PEI</i> [MJ/m <sup>2</sup> ]	1868	3225	2257
Global warming potential, <i>GWP</i> [CO <sub>2</sub> /m <sup>2</sup> ]	6	168	92

### Acknowledgement

This research work has been supported by the European Union, OP RDI project No.CZ.1.05/3.1.00/13.0283 – Intelligent Buildings.

### References

- [1] EN ISO 13830:2003 *Curtain walling – Product standard*
- [2] Tywoniak, J., Bureš, M., Volf, M., Lupíšek, A. (2014): *Curtain Walls for Building Retrofit Purposes*. Proc. Conference IEECB14, Frankfurt
- [3] Design documentation, Skanska, Division LOP, 2012
- [4] Project Pressed 06, <http://www.uceeb.cz/envilop>

## **Hybrid Roofscape – Development and experimental results of roof-integrated PV/T-collectors for ZeroEmission-LowEx building systems**

### **Authors:**

Haller, Niklaus<sup>1</sup>; Sandoval, Diego<sup>1</sup>; Nogueira, Joao<sup>1</sup>; Ruggle, Jonas<sup>1</sup>; Leibundgut, Hansjürg<sup>1</sup>

<sup>1</sup> ETH Zuerich, Dept. of Architecture, Zuerich, Switzerland

**Abstract:** Active solar energy systems have a great potential to reduce the carbon footprint of buildings. With regard to the seasonal discrepancy between supply and demand, the chair of building systems at ETH Zurich has developed a new system called “2Sol”. Low temperature heat from PV/T collectors is used to regenerate a seasonal ground heat storage. For energetic reasons, it makes sense to integrate the PV/T into the building skin. This study presents the concept of a prefabricated roof construction with integrated PV/T collectors. Experimental results from several prototypes confirm a high potential to overcome the traditional gap between energetic, economic and architectural requirements of building-integrated active solar components.

### ***ZeroEmission Architecture, LowEx Building System, 2Sol, PV/T, Building Integration***

#### **Introduction**

Reducing the carbon footprint of our built environment is one of the biggest challenges for the next decades. Despite the fact that energy saving measures at every scale, and commitments to shift from the predominant fossil to renewable energy sources can be found in governmental programs around the globe, the total consumption of primary energy and thus carbon emissions are yet not significantly decreasing. However new and even retrofit buildings could be designed as ZE-buildings and the potential for renewables in this sector is very high. Compared to the conventional energy sources, most of the renewables are subject to long or short time oscillations. That means that the question of power and reliability of the whole system becomes more and more important. New network topologies with diversified and decentralized electrical and thermal units have to be developed. Even though those topics mainly belong to the field of engineers, the whole building sector including architects, should accept the challenge. The organisation and form of the built environment has always been influenced by the energy sources and systems – but not only. After some decades of focusing primarily on the topic of energy, the discussion in Switzerland as well as in other countries with similar economical, social and climatic conditions has shifted towards a broader understanding of sustainable construction. While Minergie<sup>®</sup>, as the first established and most widespread Swiss building label has assessed only the primary energy demand for operation, the recently launched SNBS label, includes more than 25 criteria covering social, economic and environmental issues. With regard to the Swiss building sector, the main potential exists in the transformation of the existing building stock coupled with a selective (re-) densification of the urban fabric with all its positive synergies.

From an architectural perspective this shift towards a more comprehensive discussion is welcome. But do we have the appropriate tools and technologies at our disposal? In our climate, the passive house strategy for a refurbishment in a central urban area is rather difficult and completely changes the architecture. Active solar systems on the other hand burden the electrical grid and therefore externalize duties and costs. Secondly, most active solar components and systems have been developed to reach high efficiency. Building integration of solar active components has become prevalent in recent years, but only a small amount of products meet the requirements of an architecturally satisfying integration [1, 2]. As a consequence, the path is somewhere in between and should be adaptable according to the specificities of every single project. But this path must have a clearly defined designation!

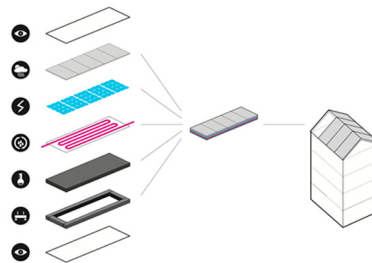
“2Sol” is the outcome of a visionary expedition called “viaGialla”, formulated seven years ago by the chair of building systems at ETH Zürich [3]. Seasonal shifting of solar energy from summer to winter to achieve an overall CO<sub>2</sub>-free operation and minimal grid reliance in winter is the concept. Passive measures are defined by the user’s comfort and the exergetic performance of the building system, not by a primary energy benchmark. A toolbox of components allows a flexible composition according to the specific requirements of the architectural design. Key players are a newly developed heat pump, a deep coaxial ground heat exchanger and low temperature distribution systems. The seasonal storage is regenerated in summer by excess heat from the building or solar thermal collectors. 2Sol systems can reach a COP of the heat pump above 8 in new and above 6 in retrofit constructions during the coldest week. All components are already on the market or will be available in 2015. PV/T collectors are especially interesting in 2Sol systems since their optimal operation temperature of 20-35°C and an average  $\Delta T$  of the collector fluid to ambient temperature in operation of 12°C perfectly matches the regeneration demand in the ground, and the electrical yield is raised through the cooling effect of the PV. An additional increase in thermal efficiency of approx. 10-15% can be attained with a backside insulation of the PV/T [4]. The main disadvantages of current PV/T are the relatively time consuming and thus costly installation and a limited variety of products. Until today it has been a niche product because it doesn’t fit into conventional solar thermal systems.

## Concept

This study presents a completely new approach to overcome the discrepancy between the theoretically perfect product and the market limitations. In a 2Sol building, PV/T surfaces are dimensioned according to the thermal need for regeneration. In a 6-story building with a moderate annual heating demand around 60 kWh/m<sup>2</sup> the entire roof must be activated. Energetic performance of the building, other heat sources as well as the orientation and hydraulics of the PV/T are variables that can be optimised. Most available PV/T products consist of a standard PV element with a module based thermal absorber. In addition to the electrical wiring every module has to be connected to the hydraulic circuit. To achieve an aesthetically pleasant installation, all those connections are done on the backside, which hinders an easy monitoring and exchangeability in case of a defective unit.



Roof constructions and PV/T modules consist of multiple layers with specific functions. At the beginning of this project all those layers have been investigated in the search of synergies and redundancy. Rather than adding energetically optimised modules on a roof, we have developed a new hybrid construction that integrates the PV/T into the building element. In the resulting design, the top layer can be any PV module with back glazing or even another heat-absorbing element. Size, colour, cell technology etc. of the modules are free of choice. They are mounted on aluminium profiles in a vertically overlapping array with joint tapes to ensure the water tightness. The continuous profiles serve as thermal absorbers and have the length of the whole element, thus the amount of connections is limited and they are accessible. Since the PV modules are cooled, additional ventilation is not necessary. The absorbers can be placed directly onto the building's thermal insulation, which simultaneously insulates the PV/T. A highly insulated wooden frame constitutes the bearing structure.



*Figure 1: Concept of prefabricated hybrid roof element with integrated PV/T collectors.*

PV modules are produced in a high-end factory line and modern computer based planning and manufacturing has renewed carpentry. But the construction site will never achieve the same level of accuracy. Once the installation is finished, the building system and its components are exposed to extreme environmental conditions and probably supervised by an untrained housekeeper but it has to bear up for 50 years. Thus it has to be simple, robust and, last but not least, it should be beautiful! Therefore we decided to leave the protected environment of simulations and lab conditions and to test the concept with prototypes at a 1:1 scale.

Regarding the long-term reliability, such a non-ventilated construction could be problematic due to accumulated moisture. Wood has the capability to absorb humidity to a certain extent but the material has to dry out again in order to maintain its structural and thermal functionality and to prevent damages caused by mould growth [5]. If ventilation is only partially enabled, moisture must be almost entirely expelled by diffusion towards the outside or inside (reverse diffusion). Thus the different layers and their respective resistance to vapour diffusion must be carefully chosen. Because of the complex geometry and non-consistent boundary conditions due to the active components it is not yet possible to depict the construction in a state of the art hygrothermal simulation tool. For this reason one prototype has been equipped with a sensor equipment to test the hygrothermal behaviour under real conditions.

### **Experimental Setup**

With the aim to investigate the feasibility of the concept, a step-by-step approach was designed. 3 Prototypes (PT1-3) have been constructed, addressing different research aspects:

PT1 consists of red a-Si PV modules, thermal absorbers, water drains and the top insulation layer. The active components have never been put into operation. PT1 was built to test general adequacy of the materials, the connections and their handling, watertightness and to analyse the ventilation effect under the absorber profiles. Considering the latter, air ducts with different patterns were milled into the insulation. A sensor network based on Arduino components [6] was developed, validated and installed to record temperature and relative air humidity (rH) in the ducts and in the insulation below.



Figures 2-4: PT1; Wood fibre insulation with milled air ducts and thermal absorber; Mock-up with red a-Si PV from outside; view from inside with backside insulation and Arduino sensor nodes.

PT2 was prefabricated in two elements with all layers (total size 30m<sup>2</sup>), installed on an existing roof and connected to the building system. One element has an additional vapour barrier on the upper OSB plate. 8 sensor groups measure air temperature and rH in different layers (Fig. 8). The gap between the existing and the new roof is used to simulate indoor conditions. Additional temperature sensors and a mass flow meter allow calculations of the thermal yield and a weather station measures outside conditions (T, rH & Irradiation on PV). All data is directly sent to a server and post-processed in a database.



Figures 5-7: PT2; Prefabrication of elements in factory hall; Installation on building B35 in Zurich.

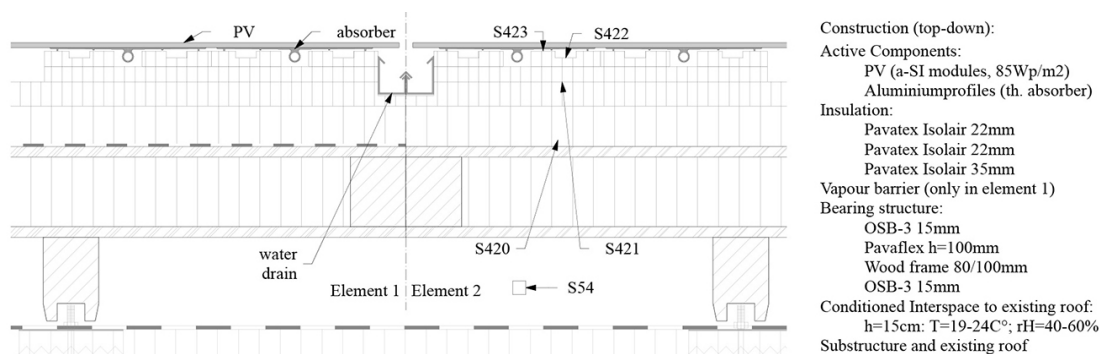


Figure 8: PT2; Cross section with constructive layers and sensor placement.

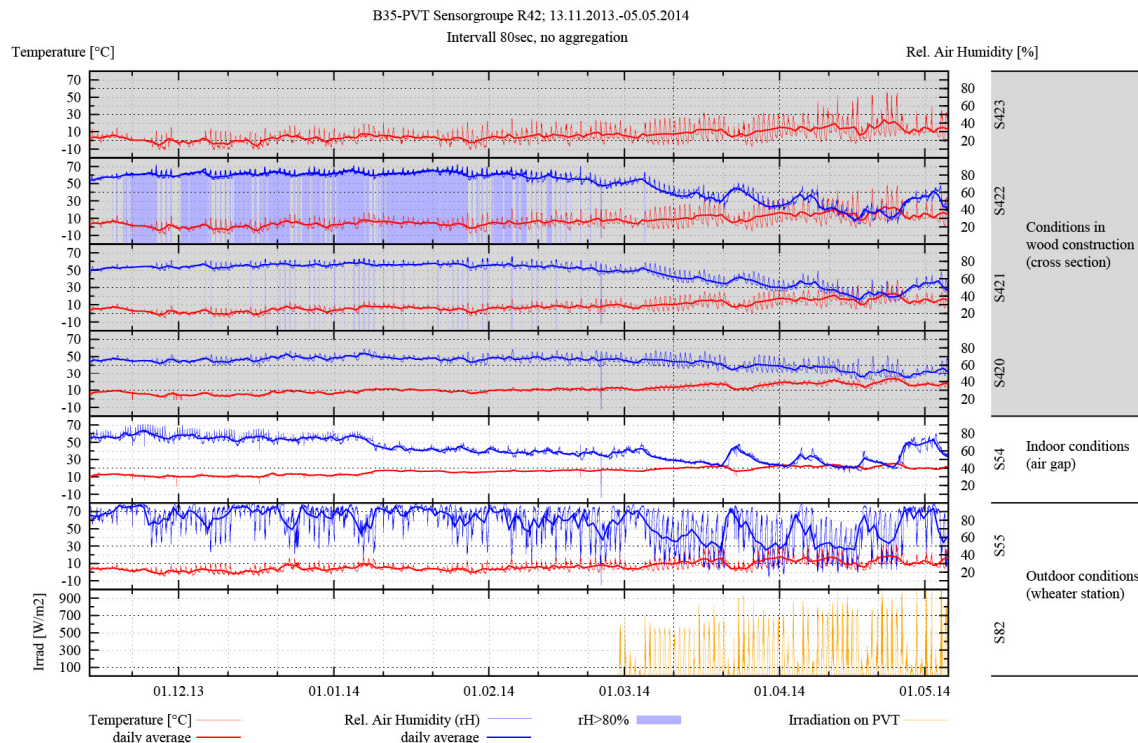
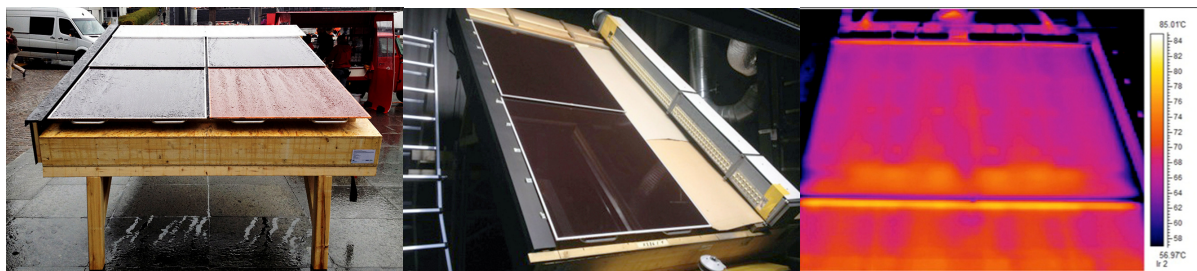


Figure 9: PT2; Temperature and rH in cross section (top-down). Irradiation was not validated before 03.14.

PT3 was examined at standard test conditions STC ( $P_{th}$  for unglazed flat plate collectors and  $P_{el}$  at MPP) at the Swiss institute for solar technologies SPF. The tests included different flow rates, the impact of wind and different thin-film PV modules. Since the PV modules are clipped onto the absorber with spring steel clamps, thermal conductance could be inhomogeneous. To increase the contact, heat transfer paste was used in an extra cycle.

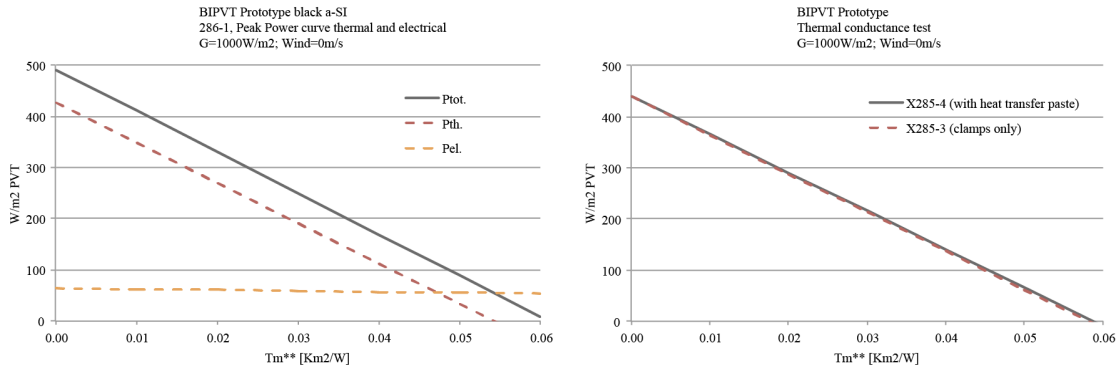


Figures 10-12: PT3; Element with coloured PV modules and façade connection; Test set-up at SPF; IR image.

## Results and discussion

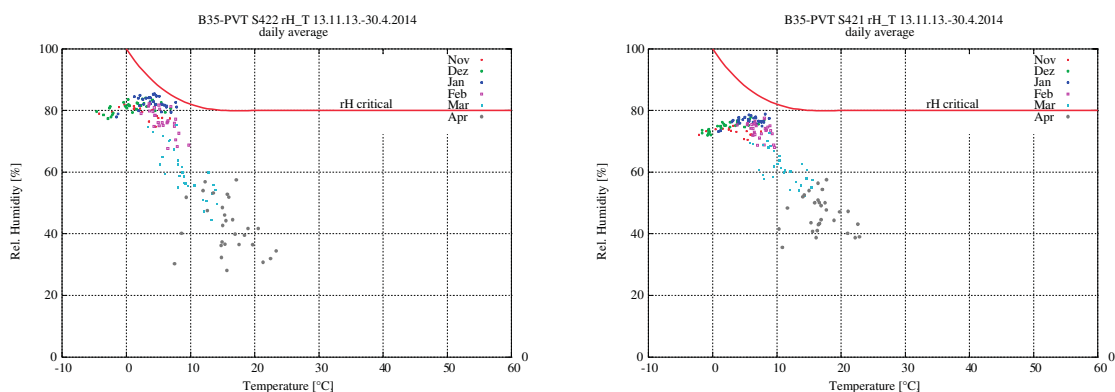
Module based PV/T on the market can reach a thermal efficiency ratio in the range of 0.5 -0.6 whereas the highest thermal efficiency ratio measured on PT3 was 0.43 (Fig. 13). The electrical output, which depends on the PV type (here a a-Si module with  $85\text{Wp/m}^2$ ) is the same. The clamps ensure sufficient contact between the glass and the absorber (Fig 14). The main reason for the lower values is a reduced packing factor due to the PV overlapping which is visible in Fig 12. The current absorber covers only 70% of the PV module, whereas this factor can reach >95% in module based PV/T. A fact to be addressed in future developments.





Figures 13-14: PT3; Thermal, electrical and total peak power; Thermal peak power with heat transfer paste to increase thermal conductance. Measurements from SPF, Rapperswil.

Considering the constructional questions, the described experiments confirm the concept. PT2 & 3 were entirely prefabricated in the factory hall and the installation of PT3 took only a few hours. This is especially interesting with regard to retrofit projects when the hybrid elements replace an existing roof. Furthermore, no water leakage was observed and the hygrothermal experiments on PT1 & 2 show that the construction is not particularly critical. Continuous measurements over six months showed that the duct layout of PT1 has no significant impact. As a consequence the absorbers of PT2 & 3 were mounted directly on the wood fibre plates and only straight cavities were done for the PV-wiring and the clamps, which simplified the manufacturing process. PT2 was installed in November 2013 and the measurements will continue for at least two more years to do a final risk evaluation. Up to now, we do not see any critical impact due to the non-existing ventilation. Fig. 9 displays the sensor group with the highest measured rH values; their placement is indicated in Fig. 8. After two months of accumulating moisture in the upper layers, the construction has dried out very quickly. Only the sensor directly placed under the absorber (S422) reaches values above 80%, the benchmark for mould growth. The recording interval is 80s and the values are undergoing high oscillations. Since the risk is depending on the respective temperature and the conditions must be stable for weeks, trends are much more meaningful [7]. In Fig. 15-16 daily mean values for the most critical sensors are compared to a temperature dependent “risk curve” [8].



Figures 15-16: PT2; Relative air humidity plot against temperature under thermal absorber (Fig. 15) and inside insulation material (Fig. 16). rH critical according to Hukka & Viitanen [8].

As a conclusion we see the biggest potential of the concept in its combination of energetic, constructional and architectural requirements. Decoupling the thermal and electrical layers of the PV/T decreases its efficiency but we argue that the requirements for building integrated solar active components go far beyond the efficiency ratio. By means of a contemporary planning and manufacturing process, multifunctional layers, thus reduction of material, installation time and inactive surface, the overall costs per m<sup>2</sup> roof can be significantly decreased without constraining the architectural aspects of design. As a consequence, such a construction is not merely planned as a solar installation but as a new hybrid typology, which covers the building, protects its inhabitants, regenerates the heat source for the winter and charges the electric car in the basement.

How effective does the collector have to be? How much is good enough?

The first privately financed installation with a total surface of 300m<sup>2</sup> will be finished in October 2014. The costs to cover the whole roof with the hybrid elements have been calculated and compared to a conventional module based PV/T system mounted on a conventional roof construction. Even though parts of the manufacturing process will still be handmade, the solution turned out to be economically more interesting. The energetic performance of the current elements is good enough to ensure a COP of the heat pump for heating and domestic hot water above 7 in winter. The thermal resistance of the façade constructions, windows etc. could be reduced to the allowed minimum according to the Swiss law for new constructions. An overall examination of this project including the total primary energy consumption, resulting CO<sub>2</sub> emissions, LCA and LCC is currently starting at ETH and will be published in 2015.

### Acknowledgements

The authors would like to thank the Federal Office of Energy SFOE for the financial support, ERNE Holzbau AG, Pavatex SA, D. Rossi and Dr. Z. Nagy from SUAT, ETH Zurich and Prof. M. Rommel and Dr. A. Bohren from SPF, Rapperswil.

### References

1. Heinstein, P., C. Ballif, und L.-E. Perret-Aebi (2013). Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths, *Green*, 3(2): 125-156.
2. Munari Probst, M.C. und C. Roecker (2012). *T.41.A.2: Solar Energy Systems in Architecture: Integration Criteria and Guidelines*. IEA SHC Task 41 Solar Energy and Architecture
3. Leibundgut, H., N. Haller, und N. Abt (2013). *ZE-2Sol*, Zürich, ITA, ETH Zürich, <http://dx.doi.org/10.3929/ethz-a-010041361>
4. Bättschmann, M. und H. Leibundgut (2012). LowEx Solar Building Systems: Integration of PV/T collectors into low exergy building systems. In: *Solar Heating and Cooling SHC*, San Francisco
5. Niemz, P. (2005). *Physik des Holzes*. Zürich, ETH Zürich
6. <http://www.arduino.cc>, accessed: 12.05.2014
7. Zürcher, C. und T. Frank (2010). *Bauphysik Bau & Energie*. Zürich, vdf
8. Hukka, A. und H.A. Viitanen (1999). A mathematical model of mould growth on wooden material. *Wood Science and Technology*, 33(6): 475-485.





## **For the last 20 years we have not heard in Russia about the sustainable development**

### **Speakers:**

Arnold, V.<sup>1</sup>

<sup>1</sup>Siberian Federal University, Krasnoyarsk, Russia

**Abstract:** *The article first focuses on the idea of 'sustainability' and the degree of prominence that this concept receives in Russia. It is based on the results of a survey of students and teachers in the Siberian Federal University in Krasnoyarsk. The text of the article presents the main possible causes of the situation and propose solutions for each of the target groups. The authors do not rely exclusively on the experience of developed countries, but also on studies of the russian scientist.*

### ***Sustainable development, Russia, survey, university***

Millions of tonnes of CO emissions, soot, exhaust gases, actual absence of sorting and recycling of waste, excessive heating and open windows in frosty days, black snow during the spring – can all this come from the one wrong word or not? Yes, it can! In Germany, for example, over the last 20 years since the introduction of the term “Nachhaltigkeit” with its renewed multi-faceted value (the same as the word “sustainability”) concept has been implemented in various spheres of human life: consumption of resources, production of new goods, construction, recycling and reuse of waste etc. This leads to the fact that not only the public in general, guided with authority, but also a single human every day many times makes his choice in favor of future generations.

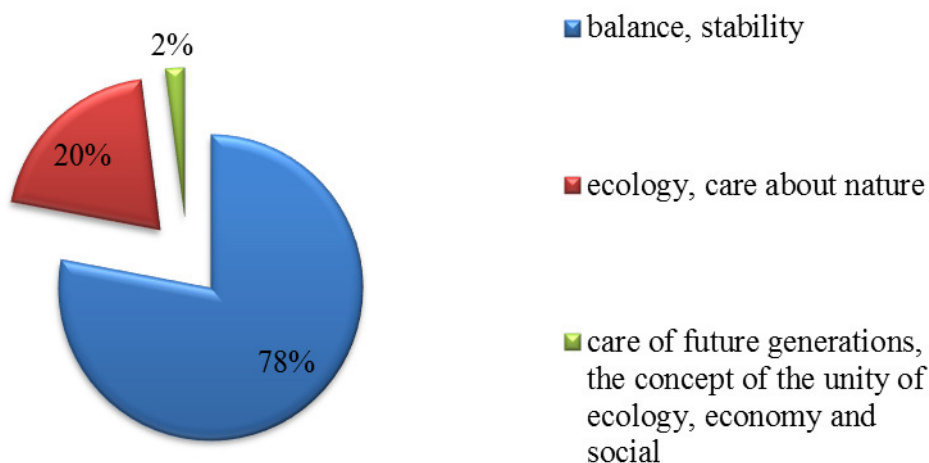
Why is the idea of "sustainable development" in Krasnoyarsk, also in Russia, not clear to every single person? There is a simple reason.

The word combination "sustainable development" or "sustainability" in the Russian language misleads and confuses people, because it literally means stable, systematic, balanced development that actually does not reflect the true meaning. Moreover, this phrase in the Russian language is inconsistent - two words "sustainable" and "development" have internal contradictory meanings. The sustainability implies balance, but development can only be when the system goes out of balance state and stability [1].

In addition, the idea of "sustainable development" is not widespread in Krasnoyarsk. It is not mentioned in the media, it is not taught in the schools and universities, besides the environmental field, it is not formed the image of this concept.

Complete misunderstanding of the concept "sustainable development" by the lecturers and professors in Krasnoyarsk conveyed the suggestion to conduct this research.

To verify our hypothesis, we conducted a survey at Siberian Federal University with a total of 40,000 students. The questionnaire consisted of 4 simple questions. The interviewees included students and lecturers. As a result, 78% of 2325 respondents have not even the faintest idea about the meaning of "sustainable development". Other 20% of respondents have mild or incomplete notion referring this concept to ecological field. Only 2% of respondents have encountered this concept and clearly know its meaning (image 1).



*Image 1 – Associations of the interviewed people with the phrase "sustainable development"*

Thus, we came to the following conclusions:

- we must enter another concept in the Russian language that would reflect the essence of the phenomenon, would be clear to everyone and not contradictory;
- we need to disseminate the idea by any known ways, bring the information to every person in order to infiltrate it in the mind.

For example, in education we offer the following methods:

- 1) for students - as a general picture of the world, with examples, tips and facts for how is it possible to reduce the consumption of natural resources at home, practical advices in a playful way;
- 2) for students - introduction of the information on lectures about what are the opportunities and what is the capacity to implement and integrate the concept of sustainable development in their future professional field;
- 3) for teachers - training courses (workshops), recommendations on the implementation of the concept in the lectures;



- 4) for bachelors and masters specialization in construction - development project must focus on the concept of sustainable development in environmental, economic, constructive and architecture sections etc.

It turns out that one word or phrase can affect the human consciousness and so change the world! So why don't we use this opportunity?

#### Reference

1. Melnik, L. (2000). Economic basis for sustainable development. Economics of Development. Schoolbook. – Sumy: University Book, p. 363-436.

## **Innovating sustainable building design and built environment processes**

Emilia, Conte; Valeria, Monno  
DICATECh, Politecnico di Bari, Bari, Italy

**Abstract:** *In this paper, we propose the concept of reliability as a way to introduce innovation in sustainable building design and built environment processes. For us reliability of agents and actions represents a new perspective for a radical restructuring of sustainability evaluation; in fact, reliability catches interactions between buildings and built environments, contextualising design solutions and stimulating the regenerative capacities of a context.*

*The paper highlights the much potential that reliability shows. It can be considered an operative tool to practice the regenerative approach; it can be a strong stimulus to innovate design activities; it can be a catalyst element of multiple stakeholders' perspectives. In the attempt to address sustainability drawing on the regenerative approach, reliability stimulates the use of new conceptual tools, implies the application of new ways of acting, and challenges our knowledge and current technologies thus promoting innovation and experimentation.*

**Keywords:** *Reliability, regenerative sustainability, evaluation, design activity*

### **Introduction**

The built environment has an enormous potential for contributing to sustainable development, but the efforts engaged for its sustainabilisation during last decades have not produced results as rewarding as expected at any level. Climate changes testify the adverse human influence on natural systems and the need to still reduce greenhouse gas emissions. At the same time, neither the economy nor society has sustainably improved in terms of viability and equity. The *greening* process of the built environment, which has been interpreted as the major way to pursue a sustainable development, is essential but also shows limits.

A major reason for this situation resides in having placed the main focus of the attention to products rather than processes. Buildings and urban environments are mostly seen as static and passive objects, subjected to more or less 'sustainable' construction and re-construction activities, rather than interacting components of a dynamic development process evolving during time and including natural and human systems. Therefore, there is a strong motivation to innovate the conceptual design tools which we use at present to address the multiple challenges of sustainability [1].

On this line, we propose the concept of *reliability* to develop an alternative methodology of evaluation to support sustainable design of the built environment. We have been studying its applicability to the evaluation of sustainability of the built environment and exploring its potential in pursuing more significant operative results than before in the design process of buildings and cities. We are almost persuaded that *reliability* offers a sensible perspective to



improve knowledge, learn innovation, and foster processes of co-creativity and co-evolution as required by the regenerative approach, acting as a catalyst element of multiple stakeholders' point of views.

### **The regenerative approach for the built environment**

Recently, some scholars have drawn attention to theory and practice of regenerative design and development [2], which offers a suitable perspective to go a step forward towards sustainability. Following such theory, human and natural systems are strictly interrelated, and their enduring life on the planet can be assured only by a proper partnership between the two systems. In this way, we can reverse the present trend, going beyond the idea of a sustainable development mainly aimed at saving natural resources and diminishing environmental impacts, and directing instead towards a regenerative development interpreted as a continuous process based on a co-evolutionary partnership between ecological and socio-cultural systems [3]. Thus, we shift from the influence of humans on natural systems to their cooperation, and re-assign to sustainability its systemic and dynamic character.

In the light of the regenerative approach, developmental processes –actions– implemented in the built environment are more important than single components –agents– constituting it; in fact, the co-evolutionary partnership necessary to produce a regenerative sustainability cannot be applied to a single building [3]. Moreover, strategies must be developed to generate co-creativity in partnership with nature, which for instance du Plessis [4] recognises in adaptation, resilience, and regeneration for an alignment of human development with the effort of nature. The built environment considered in its whole and a new way to learn and produce cooperative knowledge, evolutionary and creative, to use in practice become the urgent challenge for architects and engineers as well as all the other actors of the building process.

Then, the regenerative approach requires a profound cultural change, the only one capable of reversing the present trend of development still unsustainable despite all efforts made. Such a change is a priority, but like any other cultural modification process it needs time to mature and produce effects at both theoretical and practical levels. Meanwhile the built environment continues to be the test bed of sustainability policies and practices; therefore, an open question is whether we can improve sustainable building design and built environment processes moving from the weak sustainability of today towards a more effective regenerative sustainability.

### ***Reliability to evaluate sustainability***

According to Mang and Reed [5], different approaches and practices of sustainability are interrelated and interdependent rather than alternative or competing, and work on differentiated levels of a hierarchic structure with regeneration at the highest level. In this light, we propose the concept of *reliability* to support theoretically as well as operationally the transition of sustainability approaches and practices from bottom up in such a hierarchy.

*Reliability* is referred to both agents and actions in the built environment and expresses their



abilities to use strategies of adaptation, resilience, and regeneration. *Reliability* becomes a tool to practice the regenerative approach transversally from products –sustainable buildings– to processes –built environment development– improving the sustainability of a place (fig. 1).



Figure 1: Transversality of reliability through the process of improving sustainability

For us *reliability* constitutes a new perspective to structure a spatially sensitive method to evaluate the sustainability of the built environment. During last two decades, actors involved in the building process have learned the importance of sustainability evaluation. The proliferation of assessment systems and indicators to measure sustainable buildings and urban environments testifies the role played today by evaluation [6]. Objections can be raised concerning different interpretations of sustainability at the basis of evaluation methods and the related assessment systems, which decisively orient design choices in order to get a high sustainability score [7]. But, it is evident that they have contributed to disseminate a working mode to put sustainability into practice although in the absence of its unambiguous theorising. Therefore, opportunities exist to improve sustainability evaluation and assessment in the light of the regenerative approach, overcoming limitations of current methods and systems.

Through *reliability*, we take the opportunity of this improvement. The evaluation of *reliability* is seen as a way to challenge or push further well-established sustainable design choices and stimulate the creative dimension of the process itself. If the urban and building design is an experiment carried out under uncertainty and in the absence of experience, then it is clear from our point of view that evaluation should enlarge its horizons: from being a sort of accounting and judgment system, it should be used as a tool for thinking critically and experimenting solutions. To play this role, we rethink the conceptual fundamentals of evaluation in relation to the regenerative perspective and its underlying idea to adopt a more realistic way to see how human and natural world interact.

On the theoretical level, instead of considering buildings as passive and isolated objects in an urban environment, we consider them as evolving agents interacting with and shaping the built environment. Basing on the socio-ecological system conceptualisation [8], for us the built environment is a system characterised by a specific metabolism determined by social and ecological relationships and flows which connect agents in it. In order to get interactions between buildings and the built environment, we use the *reliability* concept. On the



operational level, the assessment of *reliability* is carried out at different levels considering on the one hand sustainability of buildings –agents– and on the other hand variations that sustainable buildings produce in the urban metabolism –actions–.

Agents –sustainable buildings– and actions addressed to make buildings sustainable are reliable if they express abilities of adaptation, resilience and regeneration [9], and convert the regenerative potential of a place into regenerative capacities, supporting the transition of sustainability towards the highest level in the hierarchy [5]. The assessment of *reliability* is based on holistic indicators, which we consider suitable for grasping relationships between buildings and the built environment. These indicators may allow quantitative as well qualitative assessment depending on *reliability* referred to agents or actions, and depending on what performances have to be assessed.

Sustainability evaluation is improved when using *reliability* since it integrates spatial scales and exploits the story and potential of a specific place, thus favouring the contextualisation of design choices as well as the identification of significant performances to be assessed.

### **Reinterpreting the design activity**

Applying sustainability evaluation since the initial phase of design allows comparing different design choices producing more effective results in terms of sustainable performances. However, while on one side simulation and evaluation have been refined on individual performances, on the other side integration of sustainable design choices lacks the right attention. On the contrary, with its complexity and uncertainty, sustainability calls for multi-competences to be integrated in design solutions for a building or an urban environment considered as a whole. From this point of view, much is still needed in order to overcome the current trend to consider sustainability related to individual performances, and even more to introduce interactions between buildings and the built environment instead of considering single objects. Through *reliability*, the authors offer a contribution in this direction promoting innovation in sustainable building design and built environment processes.

Focusing on *reliability* as defined above, the activity of designing sustainable buildings and activating built environment sustainable processes is aimed at supporting a learning process crossing boundaries between disciplines and perspectives towards a transboundary competence intended as “the ability to communicate and collaborate across traditional boundaries, while working in interaction with actors/stakeholders” [10: p.125].

*Reliability* shifts the focus of interest from products to processes and introduces contextualisation and temporal dimension into design and evaluation activities. Thinking about strategies –adaptation, resilience, and regeneration– more than solutions, architects, engineers and decision-makers as actors of sustainability processes are invited to learn and share stories about the place, and recognise its regenerative potential. Then, aims and aspirations [5] of a sustainable project will be related to that specific place and tend to translate its regenerative potential into regenerative capacities, fostering processes of co-



creative and co-evolutionary partnership between human and natural systems as the regenerative approach requires.

On this line, involving communities into the activation process of regenerative sustainability is essential. In fact, a major reason for scarce results of sustainability applications in buildings is due to people: though the increasing environmental awareness, our lifestyle is not changed much. It is still largely diffused the feeling that consuming less means less comfort and well-being, even less freedom of living choice. Therefore, we look for solutions that let us consume as much as we like, but in an environmentally compatible way. So far, this approach has generated no sensible outcomes in terms of recovering from environmental depletion and pollution, and enduring human and natural life on the planet.

Designing new buildings or improving existing buildings and urban environments in a sustainable way has not been counterbalanced by the way in which we live buildings and cities. Again, it is evident that the interaction between buildings and the built environment is essential and that the behaviour of users is crucial. Beyond green performances of a building, it is then important that the building activates interactions indoor and outdoor, with both infrastructures and users. In this way we cross the scales of sustainability evaluation and implementation and give importance to connections between agents –both human and non-human– in the built environment.

Concerning indoor infrastructures, interactions must be considered for instance in terms of rapidity of response to changing situations outside the building –temp, humidity, wind, sun radiation, rain, sounds, air pollution– as well as to uses of resources by inhabitants inside the building –heating, cooling, ventilation, water use, waste production–. In this direction, design choices should be addressed to solutions which increase the *reliability* of buildings; so that, they result as ‘relative’ solutions for a contextualised sustainable behaviour rather than ‘objective’ solutions for a context independent operation of the building.

The positive outcomes of such approach are related to many aspects. A first aspect concerns integrated design, so that the best performance of the building derives from the global functioning of the building as a whole system, with its subsystems that cooperate. This invites architects and engineers to design integrated solutions that focus on the overall behaviour of the building, avoiding design choices sustainable per se and separated from each other, in favour of solutions which are consistent internally and with place and people. A second aspect concerns the measurements, which can be still based on physical variables we are used to evaluate; but, the time variable can be added during the assessment process to represent the behavioural dynamics of the buildings. A third aspect concerns a shift of importance on building management for improving its evolving sustainability since only a complex, dedicated system of management may guarantee an effective cooperation between indoor infrastructures and their users in a specific place.

Concerning outdoor infrastructures, interactions must be considered for instance in terms of improving sustainability of other buildings, roads, open spaces, activities around a sustainable



building, and the way communities use natural and built infrastructures. In this direction, architects and engineers have to think and implement design solutions at the scale of the building itself. But, at the same time they have to stimulate a cooperative process of planning and design with other actors/stakeholders in order to intervene in the built environment with consistent and context sensitive actions aligned with efforts of nature. In such way, sustainability solutions of one building are interdependent from sustainability solutions of other buildings and urban infrastructures, and this will favour the *reliability* of actions improving both the environment and people well-being, while introducing an evolving process of cooperation suitable for turning the regenerative potential of a place into regenerative capacities.

Such an action scenario shows how a reinterpretation of design activities of buildings and built environments can be a turning point towards upper levels of sustainability, particularly on the basis of the regenerative approach. The role of architects and engineers with transboundary competences is essential in this process in order to activate cooperation stimulating co-creativity, which can express innovation and can address technological advancements experimentation.

### Conclusion

To address the multiple challenges posed by complexity and uncertainty characterising sustainability, we must innovate the conceptual tools which we use at present. In this paper, we propose the concept of *reliability* as a way to introduce innovation in sustainable building design and built environment processes. Evaluating *reliability* is a deconstructing process which is rooted in the idea that the design activity needs certainties and doubts and also capacities to transgress conventions. Thus imagined, the evaluation process becomes a companion to a creative design which opens up its routines to incorporate the whole process of production of space.

For us *reliability* of agents and actions represents a new perspective to structure a spatially sensitive method to evaluate the sustainability of the built environment. In fact, *reliability* catches interactions between buildings and built environments, contextualising design solutions and stimulating the regenerative capacities of a specific context. In the attempt to address sustainability drawing on the regenerative approach, *reliability* stimulates the use of new conceptual tools, implies the application of new ways of acting, and challenges our knowledge and current technologies thus promoting innovation and experimentation.

The paper describes the conceptual model we propose, defines *reliability* and highlights the much potential that *reliability* shows. It can be considered an operative tool to practice the regenerative approach; it can be a strong stimulus to innovate design activities; it can be a catalyst element of multiple stakeholders' perspectives. Reinterpreting the design activities of buildings and built environments can be a turning point towards upper levels of sustainability; the role of designers and projects become fundamental in order to offer and/or catalyse specific 'positives' of a place [11].



## References

1. Conte, E., Monno, V. (2012). Beyond the buildingcentric approach: A vision for an integrated evaluation of sustainable buildings. *Environmental Impact Assessment Review*, 34: 31-40, doi:10.1016/j.eiar.2011.12.003.
2. Cole, R.J. (2012). Regenerative design and development: current theory and practice. *Building Research & Information*, 40(1): 1-6, doi:10.1080/09613218.2012.617516.
3. Cole, R.J., Oliver, A., Robinson, J. (2013). Regenerative design, socio-ecological systems and co-evolution. *Building Research & Information*, 41(2): 237-247, doi:10.1080/09613218.2013.747130.
4. du Plessis, C. (2012). Towards a regenerative paradigm for the built environment. *Building Research & Information*, 40(1): 7-22, doi:10.1080/09613218.2012.628548.
5. Mang, P., Reed, B. (2012). Designing from place: a regenerative framework and methodology. *Building Research & Information*, 40(1): 23-38, doi:10.1080/09613218.2012.621341.
6. Giama, E.; Papadopoulos, A.M. (2012). Sustainable building management: overview of certification schemes and standards. *Advances in Building Energy Research*, 6(2): 242-258, doi:10.1080/17512549.2012.740905.
7. Wallhagen, M., Glaumann, M. (2011). Design consequences of differences in building assessment tools: a case study. *Building Research & Information*, 39(1): 16-33, doi: 10.1080/09613218.2010.513210.
8. Moffatt, S.; Kohler, N. (2008). Conceptualizing the built environment as a social-ecological system. *Building Research & Information*, 36(3): 248-268, doi:10.1080/09613210801928131.
9. Conte, E., Monno, V. (2014). The regenerative approach to model an integrated urban-building evaluation method. Article under review at a refereed journal.
10. Jrade, A., Jalaei, F. (2013). Integrating building information modelling with sustainability to design building projects at the conceptual stage. *Building Simulation*, 6(4): 429-444, doi: 10.1007/s12273-013-0120-0.
11. Mang, P., Reed, B. (2014.) The nature of positive. *Building Research & Information*, Commentary, doi:10.1080/09613218.2014.911565.





## **Technical knowledge transfer between Algeria and Italy: Oran, an experience of architectural rehabilitation.**

Dalila Senhadji

Architect - teacher researcher

Department of Architecture - Faculty of Architecture and Civil Engineering - University of Science and Technology - Oran – Algeria

### ***Abstract***

*At the time of globalization, the issues related to the durability of buildings in the urban areas arise with acuteness. In the case of Algeria, some answers were tempted to be brought to the social and the environmental challenges. Thus in the building field many projects are put in place in order to attempt to reduce the housing shortage. One of these solutions proved to be the rehabilitation operations of the existing buildings. The urban fabrics sometimes very degraded and sometimes out of use, are rehabilitated already with the aim to maintain the inhabitants in place. Oran, the second town in Algeria on its way to become a Mediterranean metropolis has known during these last years (2012-2014) a great impetus as far as the rehabilitation is concerned and this thanks to the political will and to the long-term vision of the local authorities. However, it has to be noted that the rehabilitation following the international norms in the building field, requires technical know-how of a high level. Thus, Italians experts specialists in rehabilitation among which some of them graduated from the polytechnic school of Turin have answered to the call launched for the rehabilitation of the colonial buildings of Oran of the XIX<sup>th</sup> century. These professionals have contributed to a huge transfer of a technical know-how between two Mediterranean regions that are Italy and Algeria. And it is in my architect's quality asked to establish technical reports on the rehabilitation construction sites that I participate to this important meeting. A privileged witness of the trainings and of the work experience from the Algerian side (the architects, the contractors, the students in architecture, the associations interested in heritage, the builders, the unskilled workers etc....), I intend to present all the transfer process of the technical knowledge. Thus, at the beginning, the trainings were done in situ following the stratigraphy operations, the setting of the scaffolding, and the dismantling of the annoying pieces on the facades, the hydro wash, the reconstruction of the moldings and architectonic treatments...etc. Thus I will explain the process of the innovation experience of technology via the architectural heritage, the transfer terms of the technical knowledge (the products and the processes) between the Mediterranean countries through a communication based on concretes tools (iconography, pictures and video reports) of the rehabilitation of Oran.*

**Key words:** rehabilitation - Knowledge Transfer -Oran - Italy



## Introduction

Oran is the second metropolitan city in Algeria of over one million inhabitants today. It has been founded in 902-903 by two Andalusian sailors and has known two Spanish presences (1509-1708)-(1732-1791) and two ottoman presences (1708-1732)-(1791-1830) before the arrival of the French in 1831. This deep historical background is translated by the peculiarity of its town planning and its architecture. The city holds an important heritage, mainly the colonial one with architectures oscillating between the neo-classic, the eclecticism, the Rococo, the modern movement..., which finds itself marginalized in a disrupted and a sprawling city. This heritage which is a major challenge in the modernization of the city of Oran, has been the object of the rehabilitation<sup>1</sup> intervention due to the building alarming report. These buildings, real jewels of the colonial architecture of the XVIII<sup>th</sup> and the XIX<sup>th</sup> centuries, go out of use due to the lack of maintenance. In 2010, a diagnosis report has been commanded by the town planning and building direction (Direction de l'urbanisme et de la construction (DUC)) to the buildings' inspection body (Contrôle technique des constructions (CTC)) concerning the old Spanish areas of Oran. First were the Algerian companies in the field, the works consisted of facades restoration with the resumption of terraces' leak tightness without worrying about the common parts. These Algerian companies are Building and Public Works companies (BTP: Bâtiments Travaux Publics) and are on any account specialized in rehabilitation. Subsequently, a call was launched for the specialized international companies, thus two Spanish companies, an Italian one and a Spanish-Algerian company were retained after decisive tests of witnesses facades. A clause has been imposed in the specifications for the training the Algerians (architects, entrepreneurs, builders, architecture students..ect). One among the major objectives from the rehabilitation experience in Oran has been the training that is presented in two categories: technical training in situ directly on the ground and the theoretical training and the ground gathering courses and practice on the sites. Our continual presence in these sites allowed us to get acquainted with the rehabilitation techniques which we restore partially here. It is not easy for us in this limited text of seven (7) pages to introduce all the rehabilitation techniques<sup>2</sup> realized on the

---

<sup>1</sup> Reminding that Oran has known its first real rehabilitation operation in 1996 with a concise financing, some buildings in the old town have been rehabilitated. A second operation was launched in 1998 in the framework of the Algerian-German technical cooperation (bilateral cooperation agreement signed the 11<sup>th</sup> February 1997 between the Algerian government (housing and urbanism ministry) and the German Deutsche Gessellschaft Fur Technicishe Zusammenarbeit "GTZ") to rehabilitate buildings in the area called les amandiers of the 1500 logements. This project (Cf.report (undated); "Projet pilote Oran cité des amandiers" OPGI Oran, 28p.) dedicated to the "improvement in the urban restructuring (Restructuration urbaine) et of the rehabilitation of the built frame (Réhabilitation du cadre bâti) in the big housing sets in Algeria", and conducted according to the planification method by objectives, it consists to put in place a rehabilitation participative approach. None of these operations has consisted of a real technical knowledge of the rehabilitation.

<sup>2</sup> All the rehabilitation techniques done on the site were illustrated with too many photographs in the framework of this text. We have also realized video reports that we have the intention to expose during the oral presentation.



site. We present here some aspects of the facades rehabilitation. A complete range will be displayed during the oral presentation including all the parts (facades, terraces and stairwell)

Oran rehabilitation buildings: a training site

In this text, i present new techniques unknown before this experience of rehabilitation experienced by the city of Oran. It is essentially a technical field work which explains the large number of photos that show the transfer of know-how between the Italian and Algerian labor work. Of course, when viewing the post, I could provide more details and explanation.

The rehabilitation operations in Oran concerned only the common parts namely : the facades, terraces waterproofing and the stairwells. These operations took place in different stages.

### **1. Outside facades and the courtyards**

The preparatory works (stripping, stratigraphy....)

The support treatments and the restoration of the facade

Restoration, rehabilitation and the facade finishing.

### **2. Waterproofing**

Accessible or inaccessible terraces and oblique roofs.

Waterproofing (watertightness).

### **3. Stairwells and common parts**

The preparatory works.

Restoration and rehabilitation of common parts

Finishing works of stairwells.

## **The outside facades.**

For the outside facades and the courtyards, we limit ourselves here to three (3) technical aspects : the stratigraphy, the hydro-wash and the rehabilitation of the modillions.

### **1.1 Faisability study/ stratigraphic study.**

A preliminary study is necessary before giving an opinion in favor of a rehabilitation project: it is the intervention . feasibility study. It includes many important points, in this case: the stratigraphic study, the photographic report, the technical and the descriptive report, the search on the material composition. The stratigraphic study never done at the rehabilitation sites in Oran, is about many intervention points of facades walls, of stairwells. The choice of these points is based on the expected rehabilitation areas.

The points raised for the stratigraphy are mentioned on a small notice where it is mentioned:

- a) The name of the site.
- b) The number of the intervention point.
- c) The date of the operation.



*Figure(1): Stratigraphy operation of the French window curves leading to the balcony*  
*Source : the author*



*Figure (2): Stratigraphy operation on a balcony console*

## 1.2 Hydro-wash operation

In order to find their original aspect, the surfaces made of stone and brick are cleaned by hydro-wash with high pressure varying the speed of water pressure following the degradation state of the treated surfaces. This operation realized by Algerians youngsters (builders, workers/laborers and students), is totally new in Oran.



*Figure (1): hydro-wash operation on the outside facades.*  
*Source : the author.*



*Figure (2) : Stratigraphy operation on the outside wall made of stone*



After the hydro-wash operation, the cleaning goes on carefully and manually with a scalpel using sometimes a thinner for a finished work.



*Figure (3) : hydro-wash operation on the architectonic treatments.*

*Source : the author.*



*Figure (4) : Finishing operation with the scalpel.*

After the hydro cleaning operation, the cleaning goes on carefully and manually with a scalpel using sometimes a thinner for a finished work.

### 1.3 Facades rehabilitation / balconies rehabilitation / modillions rehabilitation

The structural consolidation of the modillions is part of the rehabilitation operation of buildings facades. Thus, the balconies rehabilitation consisted of a structural consolidation, a dismantling and a reconstruction of the balconies floors parts with the restoration of the mouldings and the ledges. **The consolidation of the modillions went through successive stages.** The restoration and the partial structural consolidation of the existing modillions were done according to the following process: the realization of a steel armature at the inside and its binding above the balcony; the building of a formwork for filling the gaps; the structural concrete casting on the 1/3 from the moulding height; the final filling with light mortar, the artistic decorative restoration of the missing parts of the moulding and the reconstruction of the missing part and the mortar final application. We return here to the main steps.

**First step:** it is the removal of the balconies stone floor cover including the final cleaning. The cleaning of the hollow modillions by the pigeons droppings, the pigeons nests, the modillions were completely emptied.

**Second step:** start the structural consolidation of the modillions by reinforcing them vertically. Thus, the floor of the balconies are vertically drilled (holes are perceptible on the



photos) in order to insert vertically first steel rods then fill at the inside of the holes the concrete of 350kf/m<sup>3</sup>.



*Figure (5) : drilling vertical holes.*

*Source : the author*



*Figure (6) : insertion of steel metallic rods.*

The steel rods were first measured according to the modillions depth before inserting them in the holes.



*Figure (7) : Measurement and cutting of steel rods before inserting in the modillions*

*Source : the author*

### **Third step :**

Once the steel rods inserted vertically, we have proceeded the same horizontally. The modillions are then pierced face side in order to help penetrate the steel rods horizontally. holes are thus digged on the modillions face. It is important to note that the number of the rods is calculated randomly according to the importance of the modillion proportio



*Figure (8) : vertical holes drilling of small modillions to insert steel rods.*

*Source : the autor*



*Figure (9) : drilling of big modillions to insert steel rods.*



*Figure (10): view at the inside of the modillion after building a formwork with steel rods.*

*Source : the author.*



*Figure (11) : view at the inside of the modillions.*

**Fourth step:** the concrete of  $350\text{kg/m}^3$  is flowed at the inside of the modillions on the steel rods. The modillions are filled then with a light concrete (to reduce the weight). It is composed of a cement volume, a sand volume and of two polyester volumes.



*Figure 12: casting of structural concrete on the 1/3 height of the modillions and the final filling with light mortar made of expanded clay.*

*Source : the author.*



*Figure13: view at the inside of the modillions*

At the end, a decorative artistic restoration was done on the missing parts of the moulding.



Figure 14: view of the rehabilitated modillion  
Source : the author



Figure 15 : view of the rehabilitated facade

## Conclusion

The trainings on the site have allowed the transfer of a “technical” know hows, the specialization of an Algerian labor force that cannot be found before the launching of the sites. This set of techniques were the object of technical notes that we have done following the rehabilitation operation. They constitute a real capital for the very first rehabilitation operations, used at present for pedagogical and academic aims. We could not put here all the techniques developed and applied on the ground in order to respect the limits imposed for the conference. We noted that the rehabilitation according to the rules of art was unknown in Algeria Oran in general and in particular. The transfer of know-how has among other clarify the differences between the operations of rehabilitation, restoration and renovation. Rehabilitation and brings comfort to today's standards while using current techniques and materials. This experience has also helped to know the different ecological materials in the context of sustainable architecture. Before, everything had to be rehabilitated must necessarily be done with cement and sometimes very concrete by ignorance. Knowledge transfer has highlighted that we can not rehabilitate buildings built of stone in the sixteenth or eighteenth century with concrete. Different lessons are learned from this experience as said green like painting with natural hues materials ... etc.. Different types of materials used are air binders (hydraulic lime, plaster, clay) and hydraulic binders (hydraulic lime, quick-setting cement, portland cement and dairy); mortars (fat lime, hydraulic lime, bastard mortar, cement mortar, lime mortar ... etc), types of cement (blast furnace cement, pozzolan cement, white cement, portland cement); types of lime (quicklime, hydrated lime). For example, the coating of lime, which is a layer of mortar applied to a wall allows the walls to breathe and work, to prevent cracking and give a warm look to the surfaces it covers. For stucco can be slaked lime or plaster, it can be used for decorations (frames: hair, hair and mesh). Stucco slow setting is harder to work with than plaster. For mixing water can be clean water or drinking, it should not contain salt, the percentage should be between 60-70%. It is possible to obtain a mortar must be smooth and hold without dripping on the trowel (too wet mortar has a sizeable withdrawal). Mortar must be tempered as close as possible to work knowing that the transport wheelbarrow can affect the quality of the mixture. The mixing area should be clean to avoid

ISBN: 978-84-697-1815-5



earthy surfaces, then it is best to choose a concrete or asphalt surface. All these recommendations are now being applied by the hand of local Oran work in site rehabilitation.



## **The Challenge of limiting Energy Demand in Hot and Humid Regions and Mega Cities – Analyses with Integrated Building Sector Modelling**

### **Speakers:**

Bettgenhaeuser, Kjell<sup>1</sup>; Offermann, Marukus<sup>1</sup>; Groezinger, Jan<sup>1</sup>

<sup>1</sup> Ecofys, Cologne, Germany

**Abstract:** *The objective of the paper is to highlight the issue of increasing energy demand mainly due to cooling and dehumidification in hot-humid climates in the first part and to show the benefits of Integrated Assessment Modelling of building stocks in the second part. The analysis is focused on developing countries and (mega) cities and the possibilities that Integrated Assessment Models (such as the BEAM<sup>2</sup> model) offer to investigate, analyse and develop policies and technology responses to the challenges in the building sector and forecast their effects based on scenarios. Therefore the paper presents the general situation in developing countries and the main drivers for energy demand for cooling as well as the effects of renewable energy and energy efficiency measures and the functionality of the BEAM<sup>2</sup> model.*

**Key words:** *built environment, heating and cooling, dehumidification, building refurbishment, building stock, nearly-Zero-Energy-Buildings, building regulations, CO<sub>2</sub>-savings, scenario study, deep renovation, hot and humid climates, ownership rate*

### **Introduction**

About 82% of the world's population lives in less developed countries of which most of them can be classified as hot and/or humid climates. Air conditioning is not yet affordable for most households in developing countries, in contrast to US-American and European households. How will air conditioning deployment progress, if developing country incomes increase?

Household electricity consumption in many developing countries is currently low and determined by basic appliances such as refrigeration, lighting, television and sometimes washing machines or other domestic appliances (McNeil et al. 2007). The installation of air conditioning would increase the total electricity demand significantly. Considering this effect at a country level then air conditioning would contribute significantly to peak loads (problems). This may, and in some countries already does, cause chronic electricity shortages.

Air conditioning is not investigated much in colder climates, while they are generally very well evaluated regarding the energy demand for heating. The link between using air conditioning systems and income requires other approaches than for the evaluation of energy demand for heating. According to other studies, there is generally a negative correlation between wealth and exterior temperature, implying that the poorer countries are the regions with higher cooling degree days (with some exceptions) (McNeil et al. 2007). That implies that air conditioning is more desirable where it is less affordable. Thus, predicting energy demand for cooling is a rather delicate task and apart from calculating cooling loads has to





include development of ownership rates (which is directly dependent on income) as the limiting factor. Apart from increasing income, another main driver for the energy demand for cooling is the development of the population (and with it the building stock) in humid and hot regions. Most of the expected new buildings will be built in developing countries. In non-OECD countries the total building stock will double (residential) respectively triple (commercial) by 2050 while the building stock in OECD countries will increase about 30% by 2050 (WWF, 2011). The electrification and urbanisation rates are less significant since the correlation of the ownership rate of air conditioning with income is high. Households that can afford air conditioning are normally located in urban areas with electricity access.

The targets for the building sector (also in hot and humid regions) is to improve the energy performance of existing buildings and build new buildings with very low energy use. To turn these targets into action, stakeholders engaged in the process, from policy making to project implementation, need to get a clear view on the available options, costs and benefits and seek guidance on which choices to make. Generally speaking there is a variety of different measures that can be applied in order to limit energy demand for cooling and dehumidification for different climates and different building types. The starting point is always different, depending on whether measures are affecting new buildings or the existing building stock and therefore influences the options for technologies and thus costs and benefits.

### **Drivers and Problems of increasing Energy Demand in Hot and Humid World Regions and Mega Cities**

The following section discusses the main drivers for increasing energy demand for cooling in hot and humid world regions.

#### Building stock development

A main driver for energy demand for cooling is the population and the building stock development. According to UN (UN, 2012) the world's population in 2010 was an estimated around 6.8 billion and it is projected to rise up to 9.3 billion by 2050. 82% of the world's population in 2010 were living in less developed countries, of which almost all are in regions that can be classified as hot and/or humid according to Köppen-Geiger Climate Classification (Type A – C) (Kottek et al. 2006). Most of the newly constructed buildings will be in the developing countries. The residential building stock in non-OECD countries will double by 2050 and reach a total of about 380 billion m<sup>2</sup> where more than half of it will be built after 2005. The commercial building stock in non-OECD countries will grow three times by 2050 compared to 2005 (WWF, 2011). The share of households in cities in less developed regions and countries is projected to rise from 46% in 2010 to 64% in 2050 (UN, 2012).

#### Air conditioning ownership rate

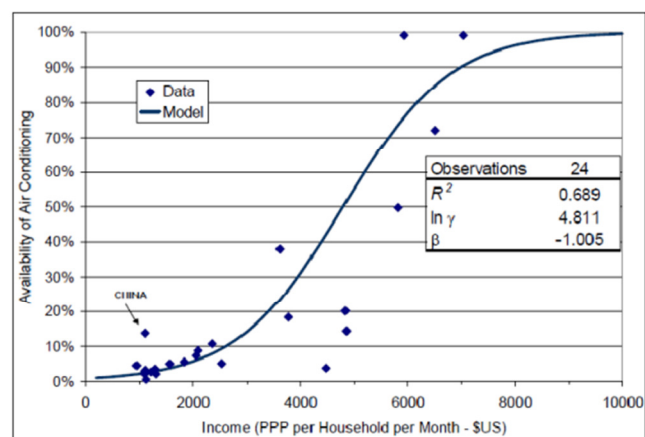
Another main driver for the energy demand of cooling is, as already mentioned, the ownership rate of air conditioning systems. In colder regions the climate is an important

indicator for the saturation of heating systems. In contrast to this in hot and humid regions, the climate determines the possible maximum saturation (and does not change over time) while income is the limiting factor. Currently many countries in hot and humid climates do not show a significant saturation rate of air conditioning (McNeil et al. 2007). With increasing income, the saturation approaches the maximum rate determined by the climate.

In developed countries where markets are nearly saturated, forecasts of market development are driven by replacements, population increase and multiple ownership. Forecasting market development in developing countries, where markets are not saturated, is strongly correlated to income.

In general, domestic appliance ownership is observed to follow an “appliance ladder”. This means that at first absolutely necessary goods (e.g. refrigerator, lighting) are purchased, followed by luxury products (e.g. washing machine, drying machine). Air conditioning is seen as a major investment that is optional.

Considering this, the possibility of purchasing an air conditioning system can be modelled as an S-shaped curve described by a logistic function according to McNeil. It is seen that initially there is a long delay before purchases take-off. Once the availability (=increasing income) “takes off”, the growth rate will accelerate (see Figure 1). It should be noted that the ownership rate may be higher than 1 since one household may purchase multiple systems.



**Figure 1: Air conditioner availability vs. income**

Source : (McNeil et al. 2007)

The impact on the energy demand for cooling, especially when coming from very low ownership rates may be high, since the rate may multiply on the short term: As a consequence the (national) energy demand for cooling will also multiply on the short term. Since air conditioning contributes to peak load, if this effect is considered at a country level it may (or does already) cause (partly) chronic electricity shortages.

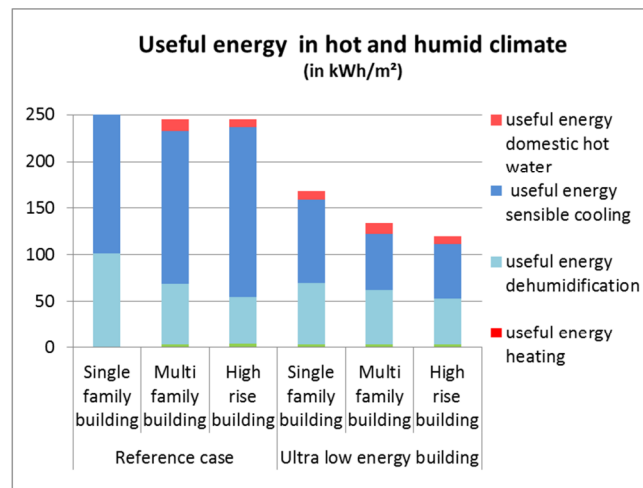
#### Costs of renewable energy or energy efficiency (RES or RUE) measures

The investment costs for the construction sector vary significantly, as a comparison of different countries shows. In general, the building costs in countries in hot and humid climates are low, or very low, compared to costs in Europe (EC Harris Research, 2012). On the other hand sustainable and renewable energy technologies don't have significant cost differences in different world regions. In developing countries with less purchasing power than European countries it becomes much more difficult to afford these technologies. When comparing the global costs, cold climate solutions tend to have better economic returns primarily because of

the higher energy prices and the comparably low cost differences for high performance technologies. In contrast, PV will often not be economic in temperate and hot regions, due to the typically lower electricity prices, even if all of the electricity generated could be used directly.

### Effects of Energy Efficiency and Renewable Energy Measures to lower Energy Demand

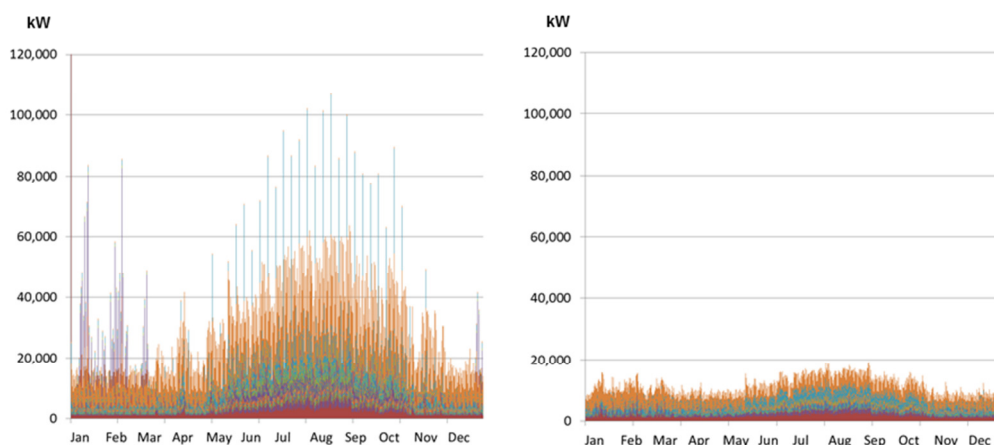
The energy demand of buildings in the hot and humid world regions (for cooling and dehumidification) are mostly higher than in the temperate or cold regions (for heating), even for highly energy efficient new buildings. The fraction of useful energy demand for dehumidification (without taking into account system efficiencies) in buildings in hot and humid regions is in the same order as the almost high energy demand for sensible cooling (see Figure 2). At the hot climate regions especially on site PV can reduce the primary energy demand significantly. For new residential building in those regions theoretically even a negative or a negligible remaining demand can be achieved. The energy demand for cooling is strongly dependent on the desired indoor comfort levels. A reduction of the maximum internal temperature, e.g. from 26 °C to 20°C, can easily lead to an increase of cooling energy demand of 50% and more.



**Figure 2: Useful energy (kWh/m²) in hot and humid climate**

Source: Ecofys own calculations (ongoing research)

Another positive effect of sustainable building concepts is the smoothing and reducing of the load curve, which also contributes directly to reducing peak loads. The following Figure 3 illustrate this with the example for a hot and arid region and compare business as usual with sustainable building concepts of a new city district.



**Figure 3: Annual load curve for electricity consumption (reference case) for different building types**

Source: Ecofys own calculations (ongoing research)

In a hot and humid region the cooling and thus electricity load would not only occur in winter but the whole year since the seasonal difference is not very distinct. With the suitable measures, it is possible to significantly eliminate the electricity (peak) load due to cooling and dehumidification.

### Integrated Assessments with the Built-Environment-Analysis-Model BEAM<sup>2</sup>

In this framework Integrated Assessment Modelling becomes very important in order to forecast possible future developments of energy demand, either as a reference scenario or a path taking into account energy efficiency and renewable energy measures in order to limit energy demand. An example of such a model is the Ecofys “Built-Environment-Analysis-Model BEAM<sup>2</sup>”, which is capable of forecasting all relevant indicators and parameters for building stocks worldwide. As data availability is often an issue in many developing countries (compared to the European situation), the model can use GDP and population numbers and forecasts if available as inputs instead of building stock inventories (number of buildings or floor area), which makes it also applicable for many regions worldwide.

Results of the model are by others energy demand, final energy, primary energy, GHG-emissions and energy costs for space heating, hot water, cooling, dehumidification and auxiliary energy in the built environment, which then can be presented for different types of buildings, building ages, climate zones. Input to the model calculation is a database containing international building stock data distinguished by climatic regions, building type/size, building age, insulation level, energy supply, energy carrier, energy costs and emission factors. This can be applied in a scenario tool used for calculating the development over time of the building stock as a function of demolition rate, new building activity, refurbishments and energy-efficiency measures in retrofits, see Figure 4. The model has widely been used in various projects, e.g. for the European Commission, associations like Eurima and EHPA and other national and international clients.

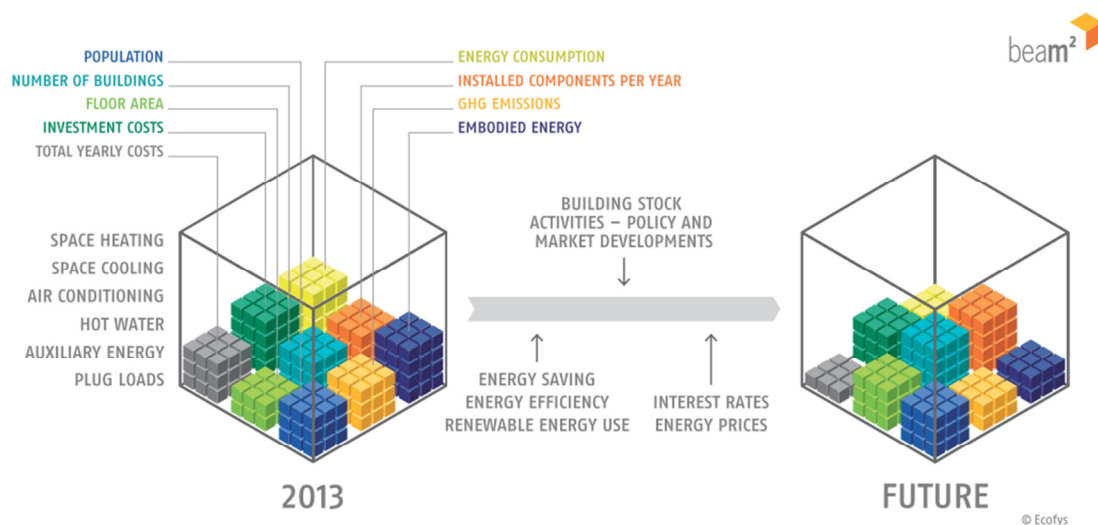


Figure 4: Structure of the Built Environment Analysis Model BEAM<sup>2</sup>

Figure 5 gives an overview of the different world regions<sup>1</sup> within the BEAM<sup>2</sup> model, which are aligned with the international UN categories. For each of these regions (or countries/cities in it) scenario calculations and analyses are possible.



**Figure 5: World Regions in the Built-Environment-Analysis-Model Model BEAM<sup>2</sup>.** Source: United Nations

## Conclusions

Most of the existing building related studies concentrate on the potentials for heating dominated regions only. They neglect the rapidly increasing energy demand for cooling and dehumidification in countries with hot and humid climates. This will be one of the key challenges to solve in the coming decade. The challenge is amplified by buildings developing into an integral part of future energy systems where they combine the function of using, producing and storing energy - as heat, cold or electricity. This highlights the fact that cities, countries and continents are in need of harmonised strategies for the next decades' developments of energy supply systems and building stock.

The integrated assessment model BEAM<sup>2</sup> (Built-Environment-Analysis-Model) is a complex building stock modelling that may be used for hot and humid regions. It offers possibilities to investigate, analyse, develop policies and technology responses to the challenges in the building sector and forecast their effects based on scenarios. The model helps to support policy actors in designing, implementing and evaluating policies for sustainable buildings in hot and humid regions. Based on the model market studies, forecasts and strategies for private companies can be developed to support future relevant decisions and advises investors and local governments on how to realise low carbon buildings and cities. BEAM<sup>2</sup> also allows to determine costs of policy measures and side effects, such adding regional values (as e.g. job

<sup>1</sup> Source: <http://unstats.un.org/unsd/methods/m49/m49regin.htm#asia>





creation). The relevant data is derived from research and innovative/leading/state-of-the-art modelling of buildings, building stocks and energy systems.

## References

- Bettgenhäuser, K. (2013). Integrated Assessment Modelling for Building Stocks - A Technical, Economical and Ecological Analysis. Dissertation TU Darmstadt D17, Ingenieurwissenschaftlicher Verlag 2013.
- Cohen, B., 2006. Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in Society* 28. 63-80.
- Ecofys, 2012. Renovation Tracks for Europe up to 2050. <http://www.eurima.org/resource-centre/publications/eurima-publications>.
- EC Harris Research, 2012: International construction costs: a changing world economy
- Givoni, B., 1998. *Climate Considerations in Building and Urban Design*. John Wiley & Sons.
- Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift* 15 (3). [http://koeppen-geiger.vu-wien.ac.at/pdf/kottek\\_et\\_al\\_2006\\_A4.pdf](http://koeppen-geiger.vu-wien.ac.at/pdf/kottek_et_al_2006_A4.pdf). 259-263.
- McNeil, M.A., Letschert, V.E., 2007. Future air conditioning energy consumption in developing countries and what can be done about it: the potential of efficiency in the residential sector. *eccee 2007 Summer Study Proceedings, Saving Energy – Just do it!*, Panel 6: Products and appliances. 1311-1322.
- McNeil, M.A., Letschert, V.E., 2010. Modeling diffusion of electrical appliances in the residential sector. *Energy and Buildings* 42. 783-790.
- United Nations, 2012. Department of Economic and Social Affairs, Population Division. *World Urbanization Prospects: The 2011 Revision, CD-ROM Edition*.
- WWF, 2011. *The Energy Report 100% renewable energy by 2050*. Gland, Switzerland.

## **Assessing the use of simplified and analytical methods for approaching thermal bridges with regard to their impact on the thermal performance of the building envelope.**

Theodoros Theodosiou, Katerina Tsikaloudaki, Dimitrios Bikas, Dimitris Aravantinos, Karolos-Nikolaos Kontoleon

Laboratory of Building Construction and building Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece

**Abstract:** *Thermal bridges have received much attention during the last decades, due to their role on the formation of the energy needs on one hand and the on-going objective for building energy efficiency on the other. Due to their complex nature, thermal bridge effect is taken into account by the linear thermal transfer coefficient  $\Psi$ . Values of  $\Psi$  can be determined by detailed numerical calculations, tabulated data or default values. The accuracy provided by each method is different and analogous to the difficulty and the burden of its implementation. In the current study, the uncertainties introduced by these methodologies are assessed by comparing the magnitude of the thermal bridge effect, calculated according to these methods on a typical building located in the Mediterranean climate. The results reveal not only the precision of each methods but also indicates the necessity of using an analytical or a simplified approach in such constructions.*

**Key words, Thermal insulation of buildings, thermal bridges, energy performance**  
**Introduction**

Thermal bridges have received much attention during the last decades, due to their role on the formation of the energy needs on one hand and the on-going objective for building energy efficiency on the other. The influence of linear thermal bridging on the energy efficiency of the building envelope is taken into account by the linear thermal transfer coefficient  $\Psi$  W/(m·K). Values of  $\Psi$  can be determined by analytical numerical calculations, thermal bridges catalogues or default values. Numerical calculations are conducted with the help of 2-D thermal analysis and finite-element software tools and are rarely employed during the building design phase due to the time consuming and complex nature of their calculation. In most cases, catalogues of thermal bridges are often used, which show the  $\Psi$  values for different configurations of the building elements, given that, typically the  $\Psi$  values vary with reference to the layers that compose the building elements in conjunction, as well as the position, the width and the properties of the thermal insulation. Default values of linear thermal transmittance are usually given for fixed parameters of typical constructional details and are used for estimating roughly the thermal bridging effect.

It is obvious that the accuracy provided by each method is different and analogous to the difficulty and the burden of its implementation. In the current study, the uncertainties introduced by these methodologies are assessed; more specifically, the thermal bridging

effects encountered in a specific building are estimated following four different methodologies:

- the detailed, numerical calculation, which has derived from the elaboration of the research project SYNERGY [1], as a representative of the finite-element, numerical approach,
- the national catalogue of thermal bridges foreseen by the Greek Regulation for building energy performance, in the relative technical guide [2]
- the default values provided by ISO 14683 [3].
- the surcharge on the U-value approach, proposed by ISO 13790 for existing buildings [4]

The first methodology is the most accurate having the least simplifications, but involves a significant calculation time and effort that is quite impossible to follow in typical building studies. In this study, it is based on the use of the finite element analysis software package ANSYS in order to simulate the actual heat flow and the linear thermal transmittance in steady-state conditions at the junction of adjacent building elements. All assumptions concerning the length of each simulated element, minimum calculation cell dimensions and boundary conditions are according to the ISO 10211[5]. An exception is that, in this method, the simplification of neglecting the influence of “secondary layers” is not taken into account. In all other methods, only the thermal insulation layer, the pillar or slab, walls and windows are considered, where other layers like plaster, floor layers, bitumen layers etc. are ignored according to the ISO 10211 (figure 1). In this method, not only all these layers are considered, but also the thickness of the insulation layer on horizontal and on vertical building elements have been calculated for all possible combinations, in order to determine the effect of this parameter to the overall thermal bridge effect.

The national catalogue of thermal bridges foreseen by the Greek Regulation is in full accordance to the ISO 10211. A large number of linear thermal transmittance is presented for a variety of building elements junctions, covering the most common construction cases found in Greek buildings. The linear thermal transmittance values are a result of analytical calculations like the first scenario, but for predetermined thermal insulation layer thickness. Additionally, only the most significant layers have been taken into account (concrete, brick blocks, thermal insulation and window frames).

Similar is the case of default, tabulated data presented in ISO 14683. The difference, relative to the previous scenario, is that this catalogue is significantly shorter, containing only the most representative cases. In order to use the catalogue, one has to make significant simplifications, like selecting geometries with limited similarity to the one under investigation. On the other hand, this catalogue is provided more like an example in order to develop national catalogues adjacent to each country’s building characteristics, and less that a complete reference table.

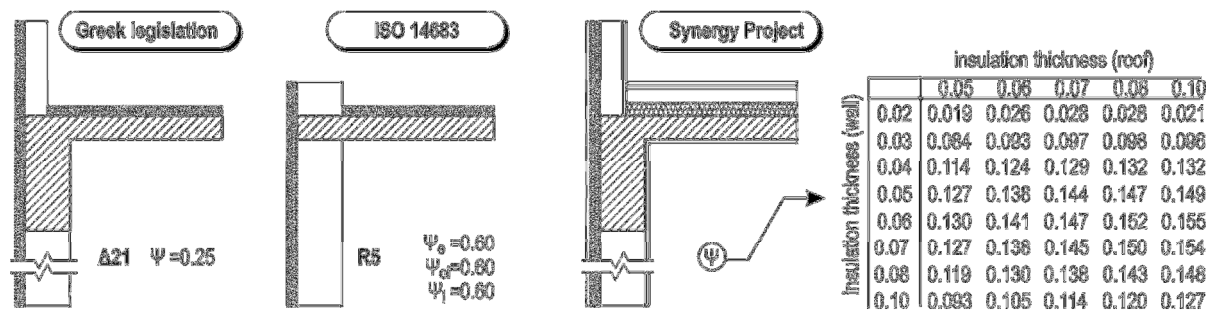


Figure 1. Example of simplification of the building elements in the examined methodologies and corresponding calculated linear thermal transmittance

Finally, the fourth method, this on applying a surcharge of 0.1 W/(m<sup>2</sup>·K) on the U-value of every opaque element, excluding elements in contact to the ground, is used mainly in existing, older buildings in the case of energy audits, since in most cases the actual construction characteristics are unknown or difficult to describe.

Methodology

All these methods are used in order to calculate the linear thermal transmittance factor of every linear thermal bridge of the building’s envelope, the average building U-value and the breakdown of heat loss according to the national thermal insulation methodology of a typical Greek multifamily building (Figure 2).

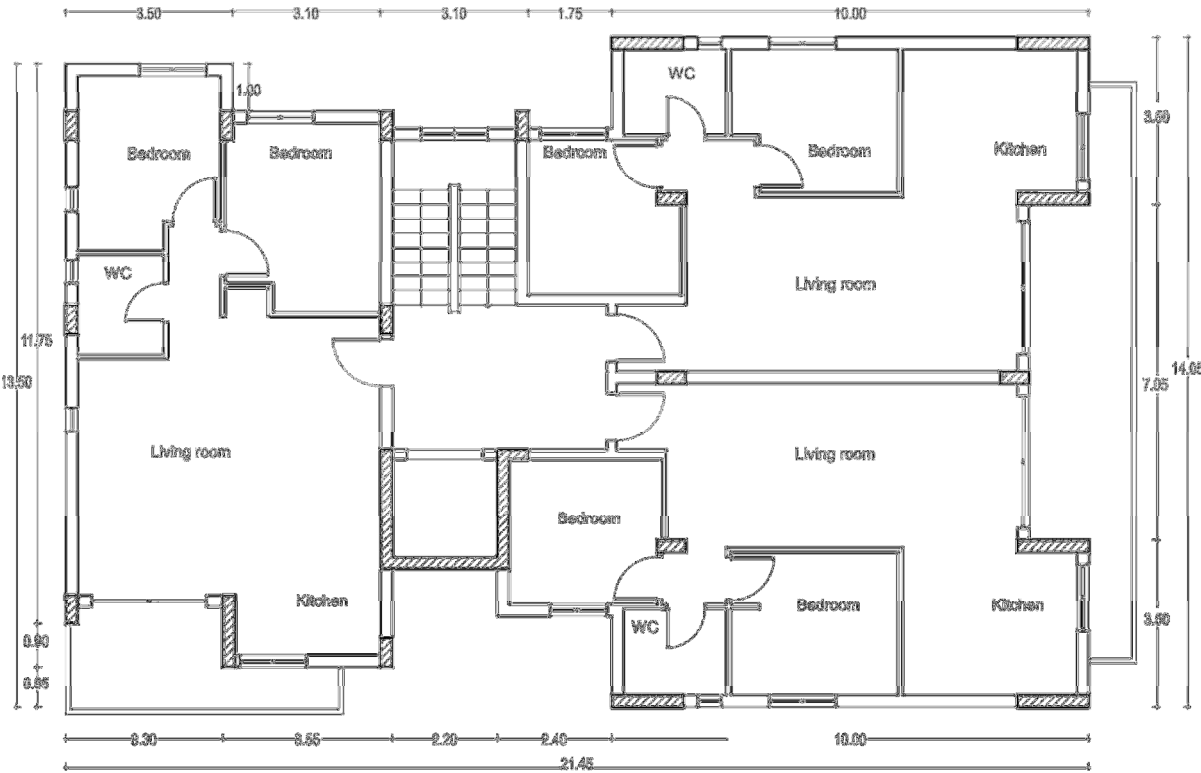


Figure 2. Floor plan of the typical multi-family building.

Like almost every building of the residential sector in Greece, the existence of balconies and other morphological characteristics of the envelope contribute to a relatively large proportion of heat loss due to thermal bridge, which can account for up to 30% or even higher of total thermal loss through the envelope [6]. Obviously, such a relatively large contribution to heat flows plays an important role in modern legislation requirements and are supposed to become even more significant in near future, where low or near-zero building principle demands accurate estimation of actual heat flows.

The results of each methodology, are presented for each of the four climatic zones in Greece, since actual thermal insulation requirements vary according to the climatic zone. The difference lies in the fact that the maximum allowed overall thermal transmittance of the envelope differs among climatic zones, being higher in the warm climatic zone (zone A) of southern Greece and lower in the colder zone of northern Greece (zone D). Thickness of insulation layers in every building element varies accordingly from 5 to 7 cm. Regarding the magnitude of thermal bridge effect, the different insulation thickness of envelope elements in each zone, results in different linear thermal transfer coefficients in the analytical methodology, where in all other cases, the thickness of the insulation layer does not affect this, due to calculation assumptions.

## Results

The comparison of the calculated heat flows does not only reveal the precision of each method –compared to the numerical method- but it indicates the necessity of using an analytical or a simplified approach in the Mediterranean building constructions, where the thermal losses due to the existence of thermal bridges are significant, as the balconies interrupt the continuity of thermal protection.

Figure 3 presents the breakdown of thermal bridge heat transmission for each of the examined methodologies. According to the results, the use of tabulated data from ISO 14683 can lead to the higher overestimation of thermal bridge effect. Depending on the level of insulation protection, in low thermal insulation requirements like those in zone A, the estimation error of this methodology can lead to a 94% overestimation in the typical building, while in better insulated buildings like those in zone D, the error is reduced to 69% but remains significant. The larger error is found in the estimation of horizontal thermal bridges, while vertical ones are underestimated by ISO 14683 methodology.

Tabulated data found in the Greek technical guides present a similar overestimation, but with a lower error varying from 86% to 63%, depending on the climatic zone. The more simple form of vertical thermal bridges, like those found in the corners of the building contributes to a small estimation error. On the contrary, the error of vertical thermal bridges is significant.



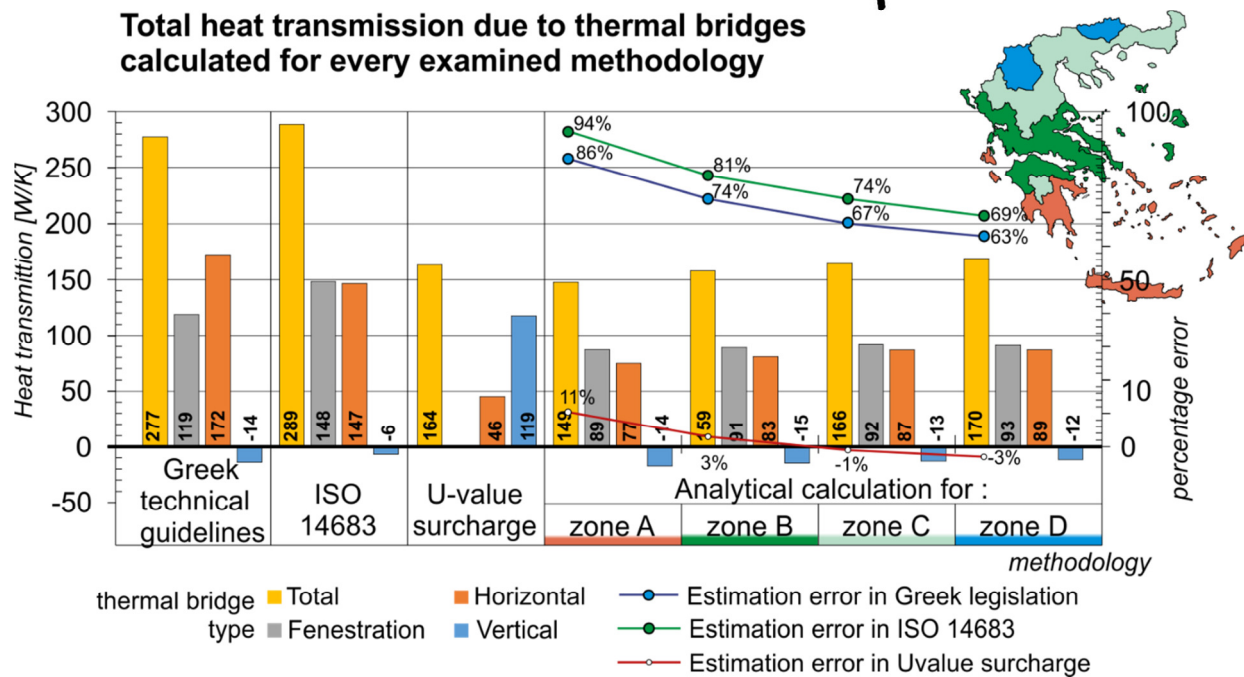


Figure 3. Breakdown of thermal bridge heat transmission according to all examined methodologies

Finally the methodology that surcharges the U-value of opaque elements despite being the simplest among the studied here, proves to be relatively accurate on overall heat transmission in the examined building, since it has a small estimation error, underestimating the actual heat flows. Unfortunately, this accuracy is related mainly to the specific characteristics of the study and can be considered as a random result. This is quite obvious from the breakdown of these heat flows, where vertical thermal bridges are highly overestimated and horizontal thermal bridges underestimated.

From these results, it is obvious that simplified methodologies that neglect the actual layers of the building elements and are not related to actual insulation layer thickness, tend to highly overestimate actual heat flows due to thermal bridge effect. When these heat flows are calculated using the more accurate, analytical methodology, the magnitude of thermal bridging is analogous to the level of insulation protection. This is expected, since heat flow in the area of a thermal bridge is relatively unaffected by the insulation thickness. In highly insulated buildings this magnitude is a larger portion of overall heat flows [7].

#### Heat transmission through thermal bridges as a fraction of total heat flow through envelope

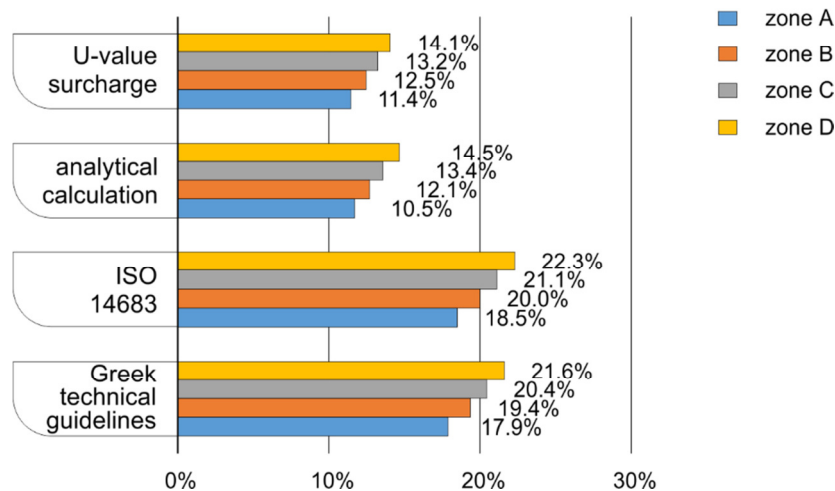


Figure 4. Percentage participation of thermal bridge heat transmission on overall heat transmission through the building's envelope.

The portion of heat flows due to thermal bridge to overall heat flows through the building's envelope is presented in figure 4. The presented error of up to 86% in existing methodology in Greece could be insignificant if thermal bridges was a minor heat flow. Although, the presented building is not among those where thermal bridges account for even up to 30% of overall heat flows, still their role cannot be neglected. According to national methodology applied to the selected building, thermal bridges are responsible for 18% to 21% of total heat flows, depending on the climatic zone. The application of the tabulated data of ISO 14683 presents similar results. The more accurate analytical method decreases these values to 15% and 11% respectively. Although a 10% error in estimating heat flows could be accepted some years ago, where applied methodologies were not very demanding, nowadays and especially in the near future, such an error in one of the more easy to estimate heat flows, like conduction heat flows, introduces a significant uncertainty regarding the tools we use to achieve low-energy and sustainable buildings.

## Conclusions

The application of different methodologies to estimate the linear thermal bridge effect on a typical apartment building, shows that although all these methodologies are according to European standards, results differ by large amount. The most common approach to use pre-calculated, tabulated data for a variety of building elements tend to significantly overestimate the role of thermal bridges, by almost doubling their magnitude. In better insulated buildings, like these in the colder climatic zone of Greece, the error decreases but still cannot be neglected.

Surprisingly, the simplest methodology of surcharging the U-value of opaque elements, results in an estimation of the thermal bridge effect magnitude that is closest to the analytically calculated values. Unfortunately, the analysis done here cannot support that this



method could successfully replace more complex methods. On the contrary, despite the total heat flow due to thermal bridges, the relative heat flows due to horizontal, vertical and fenestration thermal bridge are rather accidental and cannot be scientifically supported.

If national requirements were more demanding, similar to these in northern Europe, then the error would be expected to decrease even more. In that case, the application of relevant standards might be more accurate.

The use of accurate, numerical methods can be considered as not realistic in building studies since they could increase significantly the cost, time and complexity of the study.

Unfortunately, in the case of the Mediterranean climate, the direct application of the other, simplified methodologies and standards should be reconsidered since the overestimation is not in accordance with modern methodologies that seek a more accurate estimation of heat flows and energy consumption. A more extended study is needed in order to adjust these standards to the national thermal insulation requirements. In that way, the estimation of thermal bridge effect could more realistic and could better support the need of improving methodologies aiming to design or verify the energy performance of buildings.

## References

- [1] D. Bikas, et al., The Synergy Project: A Study of High Energy-Efficient Building Elements Assessed under Integrated Protection Criteria and Life Cycle Design Aspects, in: Civil Engineering for Sustainability and Resilience International Conference, CESARE '14, Amman, Jordan, 2014.
- [2] T.O.T.E.E. 20701-2/2010. Thermophysical properties of building materials and thermal insulation requirements, in: T.C.o. Greece (Ed.), 2010.
- [3] EN ISO 14683, Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values, (2007)
- [4] EN ISO 13790, Energy performance of buildings — Calculation of energy use for space heating and cooling, (2008)
- [5] EN ISO 10211, Thermal bridges in building construction - heat flows and surface temperatures - Detailed calculations, (2007)
- [6] T.G. Theodosiou, A.M. Papadopoulos, The impact of thermal bridges on the energy demand of buildings with double brick wall constructions, *Energy and Buildings*, 40 (11) (2008) 2083-2089.
- [7] K. Tsikaloudaki, et al., Quantifying the thermal bridging effect with regard to the facade's configuration, in: *Places & Technologies*, Belgrade, 2014.

## Energy Saving Benefits of Daylighting Combined with Horizontal Exterior Overhangs in Hot-and-Humid Regions

### Speakers:

Huang, Kuo-Tsang <sup>1</sup>; Fu, Chun <sup>2</sup>

<sup>1</sup> Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei, Taiwan

<sup>2</sup> Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei, Taiwan

**Abstract:** *The exterior shading is an effective way to reduce heat gains through blocking the radiation. However, it also reduces the daylight availability, causing increased artificial lighting energy consumption. The purpose of this paper is to investigate the impact of various overhang design combinations on HVAC and lighting energy use considering visual comfort. EnergyPlus is used for energy related simulations whilst daylight is simulated by DAYSIM. The results show that building fenestration orientation and its opening area ratio mainly influenced the energy consumption and visual comfort. The performance of the optimal design regarding the exterior setup as well as building fabrics are also discussed.*

**Keywords:** *visual comfort, energy efficiency, exterior horizontal overhang, Taguchi method*

### Introduction

In the subtropical regions, because there is a great amount of solar radiation during the whole year, which causes high temperatures in indoor environment, more cooling requirement is needed to reduce thermal discomfort. Thus, the exterior horizontal overhang is an efficient means to reduce the indoor heat gain via direct solar irradiance. However, the exterior overhang also prevents the daylight entering into indoors, causing increased artificial lighting energy consumption. The use of lighting would also contributed to the cooling load and burdens the cooling energy. Besides, visual comfort, which considers both the degree of illuminance and the sunlight glare, should be considered when utilizing daylighting design.

There have been many previous studies concerned with efficiency and impact of the overhang. Ho [1] investigated the optimal design of external shading device in a classroom in subtropical Taiwan, and the target is to minimize the lighting power cost. Besides, he also calculated the uniformity of the classroom to evaluate visual comfort. David [2] studied the effect of different sizing of shading devices and assessed cooling load, artificial lighting, and visual comfort in tropics. Different types and varying d/h (d: depth of shading; h: window height) of shading devices are studied. Lim [3] conducted an empirical study for a government office building and compared the field measurement with the result in simulation tool Radiance in order to validate the accuracy of Radiance. Second, some modifications of shading device were simulated to assess the effect on visual comfort, such as Visual Comfort Probability (VCP), CIE Glare Index and uniformity. However, relatively few research discussing on the overall impacts on both total energy consumption and the visual comfort

simultaneously. As exterior shading lowers the heat gain from solar irradiance, the additional artificial lighting heat discharge due to insufficient illuminance would also increase air conditioning energy, the interactive behavior between them is necessary to be discussed in achieving optimal energy balanced passive design. In terms of visual comfort, the available daylight as well as daylight glare should be considered, and they are easily neglected while minimizing the total energy consumption.

The aim of this research is to quantify the energy conservation benefits considering visual comfort and to propose proper exterior shading design parameters in a typical office building situated in hot-and-humid Taiwan. To this end, we choose two software as our simulation tools: EnergyPlus and DAYSIM. The former one is a well-known software in simulating building energy field, which has reliable accuracy in simulation of energy consumption. Although EnergyPlus is capable in simulating daylight, previous study pointed out that it has some limitations and as not accurate as Radiance [4]. DAYSIM is developed based on Radiance's algorithms and have been well developed and widely validated. It is proved as a reliable software in simulating daylight [5]. Therefore, EnergyPlus coupled with DAYSIM were adopted in this study.

### Methodology

As shown in Fig. 1, research consists three major parts, (1) choosing factors and design of experiments, (2) daylight and energy consumption simulation, and (3) the analysis of the impact. To understand the impact of shading designs on energy use and visual environment under different design setup, the properties of horizontal overhang has been studied. The orientation of the building, glazing types, and Window to Wall Ratio (WWR) are also considered. Lighting and HVAC energy consumption were assessed by simulation, and the relationship between them is also discussed. Useful Daylight Index (UDI) and Daylight Glare Probability (DGP) were used to evaluate the daylight availability and daylight glare respectively. In DAYSIM simulation, since generating annual illuminance data and DGP in each possible simulation run is time-consuming, the exploration of all the parameter combinations is impractical. Therefore, design of experiment technique (Taguchi method) was used to arrange the experiments efficiently for reducing large number of simulation runs.

### Geometry and parameters of the model

The reference model in this study is a typical office room located in hot-and-humid Taiwan. The office room is a middle floor of a multi-story building, which ceiling height is 3.5 m, 11.5 m in width and 6.3 m in depth, the total floor area is 72.45 m<sup>2</sup> as shown in Fig. 2. The room has a window on the daylight side, whose width is identical to the width of the room. The wall with the window is the only exterior wall that exposed to outdoor air, and the coefficient of thermal conductivity (U-value) is 2.77 W/m<sup>2</sup>K. All the interior walls in the model are assumed to be adiabatic as the adjacent spaces are of the same air-conditioning conditions. The office occupancy on weekdays is defined as 0.2 person per square meter, and it decreases to 0.1 at the lunch time (12:00-13:00) and near the evening (17:00-18:00). The equipment power density is 10 W/m<sup>2</sup>, and the schedule of equipment is the same as the occupancy



schedule. The lighting schedule was determined based on the averaged indoor illuminance results simulated from DAYSIM. Parameters and their levels used in orthogonal array experiment are listed in table 1.

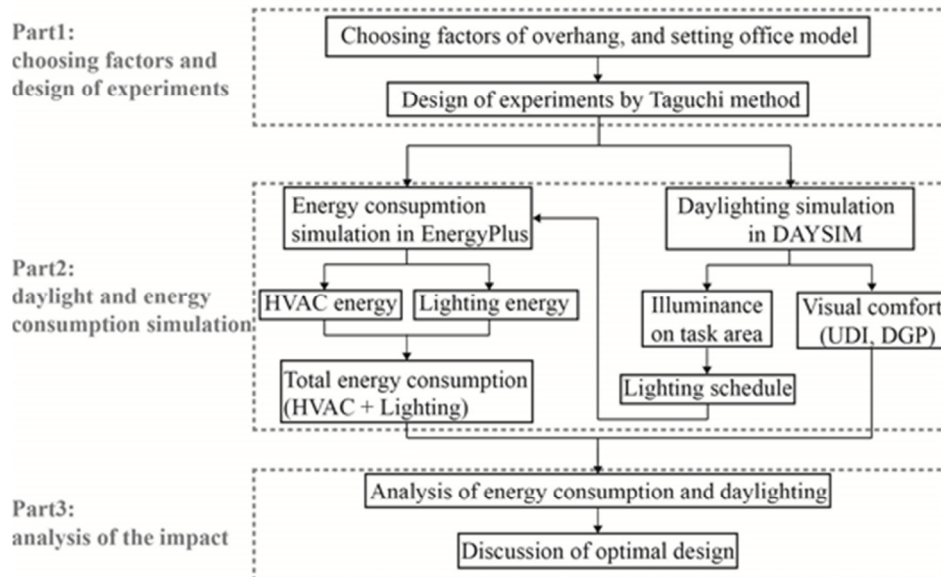


Figure 1. The research scheme

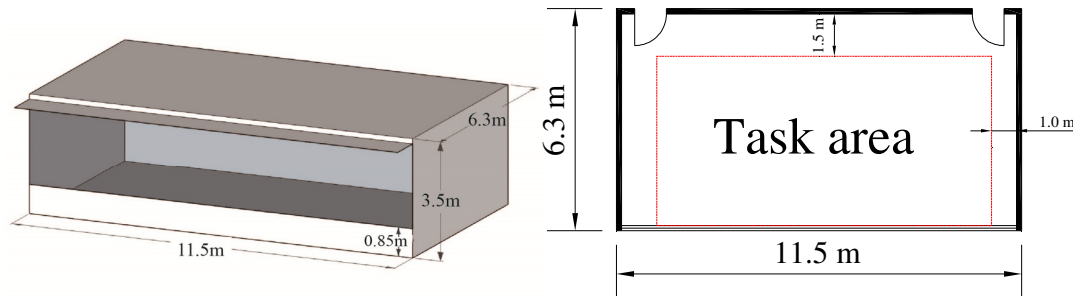


Figure 2. The geometry of the office model and the task area

Table 1. Levels of all factors (including geometry and material properties)

	Orientation	Depth	Position ratio	Reflectivity	Tilt angle	WWR	Glazing
Level 1	(8 levels:	1.0 m	1.00	70%	90°	70%	Single Clear
Level 2	N,NE,E,SE,	0.7 m	0.75	50%	70°	50%	Single Tint
Level 3	S,SW,W,NW)	0.5 m	0.50	30%	45°	30%	Dbl. Low-E

Four design factors of the exterior horizontal overhang shading are discussed, which are overhang's depth, vertical relative position to window of the overhang, tilt angle, and the shading's material surface reflectivity. The vertical relative position of overhang is defined as Position Ratio, which is calculated as the ratio of the overhang's vertical distance from the sill to the window's height. Position ratio of 0.5 means the overhang is located in the middle of windows height. Tilt angle is defined as the angle between the shading plate and the wall. An angle of 90 degrees means the overhang is installed perpendicular to the wall. Three types of overhang materials with various colors and surface reflectance are chosen.

## Design of Experiments

To carry out all the possible parameter combinations listed in table 1 is time-consuming and the number of total simulation runs would be as high as 5832 times which is deemed impractical. Therefore, Taguchi method, which is an efficient statistical design of experiments, has been applied to minimize the runs of experiment. Taguchi orthogonal design table of L27 ( $3^{13}$ ) was chosen in this case. However, the factor of orientation has 8 levels while there are only three-level columns in L27. To resolve this problem, column-merging method was adopted to combine 4 columns into 1 column to accommodate the orientation parameter.

## The Assessment of Daylight Availability and Visual Comfort

Daylighting was simulated via DAYSIM. The reflectance of ceiling, wall and floor are 0.8, 0.5 and 0.3 respectively. The height of the work plane of interest is 0.85 m above floor. The task area of the office is 9.5 m wide, 4.8 m deep (see Fig. 2). This task area is near the window, and the view direction of the occupant which is used in calculating DGP is perpendicularly vectored outward to the window. Useful Daylight Index (UDI), which is used to quantify useful daylight illuminance within the range of 300-2000 lx is used to characterize the illuminance quality by daylight. Daylight Glare Probability (DGP) is an index to represent the probability of experiencing discomfort glare. There are four categories of the DGP values: intolerable ( $DGP > 0.45$ ), disturbing ( $0.45 > DGP > 0.4$ ), perceptible ( $0.4 > DGP > 0.35$ ), and imperceptible ( $DGP < 0.35$ ). The percentage of annual work hours in which the DGP is less than 0.4 is considered acceptable herein the study. The minimum illuminance level of 500 lx suggested in ISO 8995 for task area is used as minimum requirement of task illuminance. The lighting switch on/off schedule used in EnergyPlus energy simulation is determined by illuminance map output from DAYSIM simulation. The artificial light is switched on with dimming control to maintain the illuminance level in all the task area above 500 lx. This lighting schedule was afterwards fed to EnergyPlus to simulate the annual lighting energy.

## Energy Consumption Analysis

Fig. 3 indicates the mean effects (compared to the mean value of total 27 experiments) of factors on energy consumption, and the energy use is assessed with Energy Use Intensity (EUI) index. Both HVAC and lighting energy consumption is influenced mainly by orientation, WWR, and glazing types. Overall, south-facing and north-facing cases save more total energy than other directions. The influence of WWR is very different between HVAC and lighting. WWR of 30% causes a relatively high mean effect of 3.6 kwh/m<sup>2</sup>.yr because the lighting demand is much higher than the average value. In contrast, WWR of 70% may save more energy for the total mean effect is -0.4 kwh/m<sup>2</sup>.yr. Double low-E glass may lead to higher lighting energy while single clear glass has higher HVAC energy.

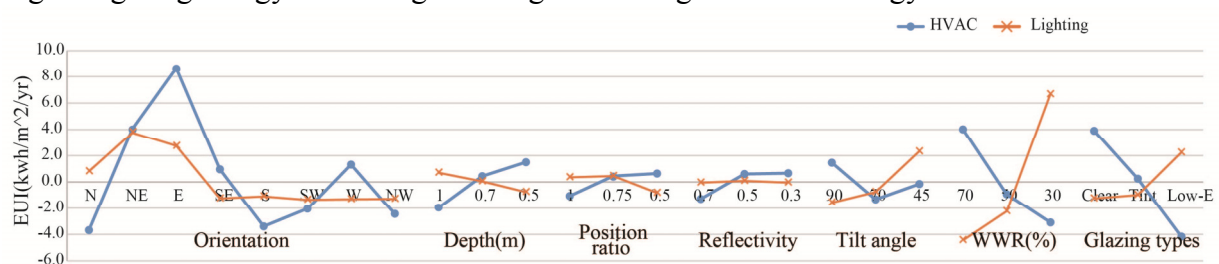


Figure 3. The mean effects of all factors on EUI (including HVAC and lighting)

### Visual Comfort Analysis

As shown in Fig. 4, there are more available daylight in the directions of N, NW, and NE. Among all factors, WWR have the greatest influence on the value of UDI. WWR of 70% have a mean effect of -11.6 %, while 30%WWR have a mean effect of 8.8%. Although the cases with high WWR or in the directions such as east or west have more sunlight from the window, the illuminance level is too high and would cause less useful daylight. The reflectivity of 0.7 has a mean effect of -2.9 % suggesting that higher reflectivity seems to have negative effect on daylight utilization. Similarly, the directions of N, NW, NE, and lower WWR would have more times in which DGP is acceptable for people ( $DGP < 0.4$ ). Because the experiment no. 7 (WWR of 30% with tilt angle of 45 degrees) has scarce daylight, the UDI is as low as 32.6 % resulting no glare occurred in all year. This situation greatly influence the mean effect of east-direction, so there is an obvious difference of mean effect between east and west.

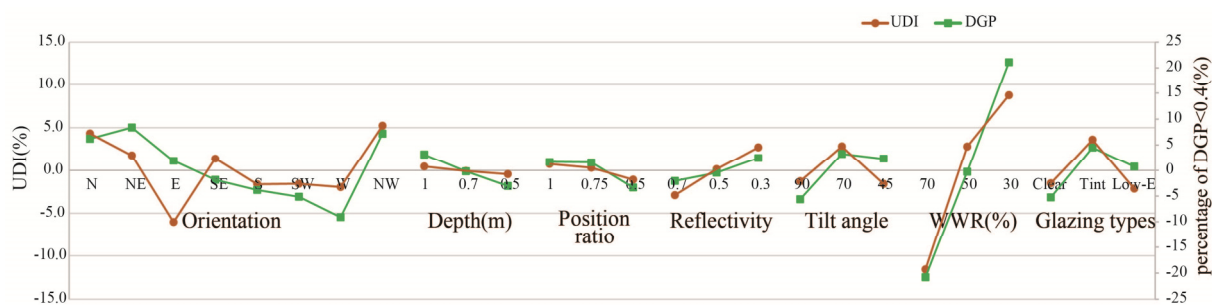


Figure 4. The mean effects of all factors on visual comfort (including UDI and DGP)

### The Optimal Design

To study the relationship between energy consumption and daylighting, the 27 main effects of total energy, UDI, and percentage of  $DGP < 0.4$  are plotted in Fig. 5. From these two figures, it reveals that data points concentrate in the bottom-right and top-left parts. This tendency indicates that the pursuit of high energy saving may possibly decrease visual comfort. To determine the optimal solution, the average lines are drawn to divide the graph into four parts. The bottom-left part means low visual comfort (including UDI and DGP) and high energy consumption, which is the worst among all parts. The bottom-right and top-left, in which most plots fall, are either having low visual comfort or high energy consumption. The best part, which is the top-right with good visual comfort and low energy consumption, have total 3 points in this area. These 3 points are experiment no. 2, 10 and 23. Although they are not the best choice with respect to visual comfort or energy saving individually. It's quite difficult to achieve maximum energy saving and the best visual comfort simultaneously, balanced compromise should be considered.

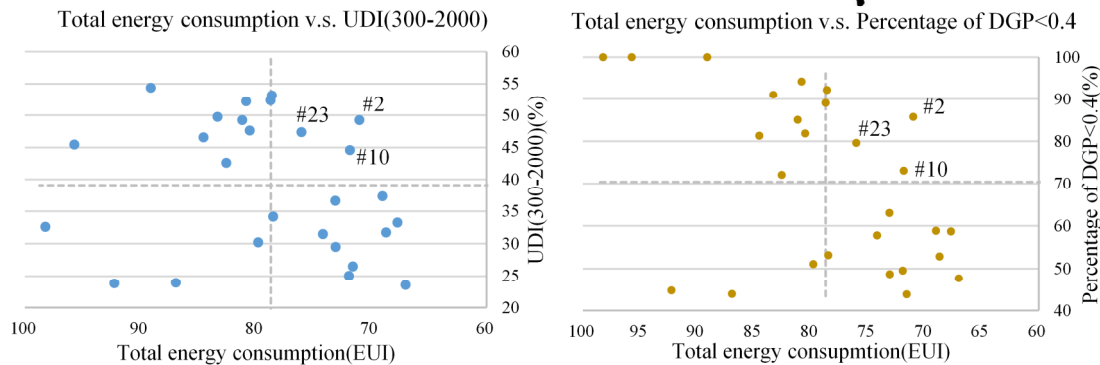


Figure 5. Plots of the total energy consumption and visual comfort

Among the experiment no.2, 10 and 23, no. 2 has better energy saving and visual comfort, thus it is discussed in Fig. 6 and 7, which is a false-color map where the X-axis is the day of year and the Y-axis is the time of day, is used to present annual variations of UDI and DGP. Another facing north case, experiment no. 1, with worse visual comfort is also presented as a contrast. It is obvious that no. 2 have less daylighting glare during the whole year. However, no. 2 still has 14.2% of total work hours in which people experience unacceptable glare. It is noticeable that useful daylight of no. 1 is much less than no. 2 near the noon. This situation can be compared to the figure of DGP, as Fig. 7, it is found that the time of experiencing more daylighting glare also accompanied with decreased amount of useful daylight. The main reason for visual discomfort in experiment no. 1 is the high WWR of 70%, which caused much more over illuminating areas indoors, while WWR of no. 2 is just 50%.

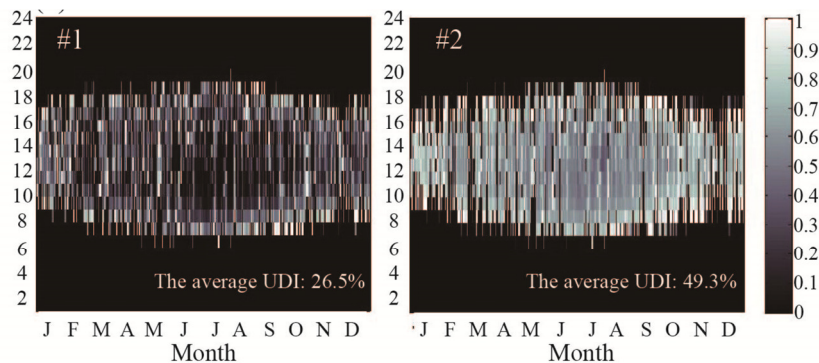


Figure 6. Temporal map of UDI for experiment no. 1 and no. 2

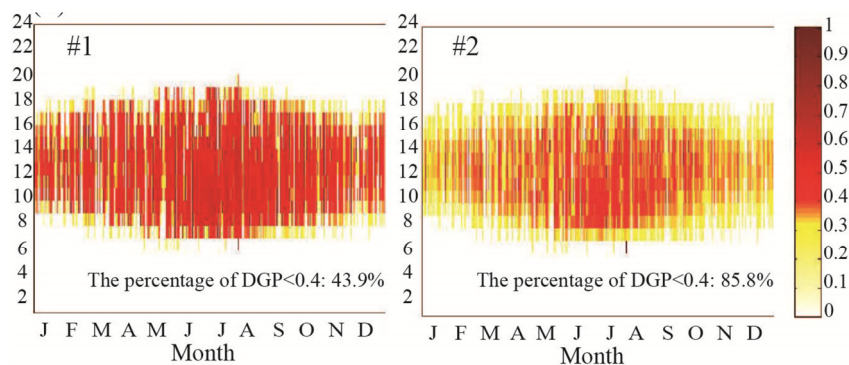


Figure 7. Temporal map of DGP for experiment no. 1 and no. 2



## Conclusion

In this study, several horizontal overhang shading designs were investigated in subtropical Taiwan, in terms of both energy consumption and visual comfort. From the analysis of the simulation results, several conclusions can be obtained as follows:

1. South and north directions are beneficial for energy saving, but north-facing cases have better visual comfort.
2. WWR greatly influences both energy consumption and visual comfort. Although WWR of 30% has more lighting demand, it still has better energy saving (due to less HVAC energy) and visual comfort than WWR of 50 and 70%.
3. Among 27 experiments, no one achieves minimum energy consumption and best visual comfort at the same time. However, it is possible to strike a balance between them and having remarkable effect.

## Reference

- [1] Ho, M.-C., et al. (2008). Optimal sun-shading design for enhanced daylight illumination of subtropical classrooms. *Energy and Buildings*, 40(10): p. 1844-1855.
- [2] David, M., et al. (2011). Assessment of the thermal and visual efficiency of solar shades. *Building and Environment*, 46(7): p. 1489-1496.
- [3] Lim, Y.W., et al. (2012). Building façade design for daylighting quality in typical government office building. *Building and Environment*, 57: p. 194-204.
- [4] Ramos, G. and E. Ghisi. (2010). Analysis of daylight calculated using the EnergyPlus programme. *Renewable and Sustainable Energy Reviews*, 14(7): p. 1948-1958.
- [5] Reinhart, C. and B. Pierre-Felix. (2009). Experimental validation of autodesk® 3ds max® design 2009 and daysim 3.0. *LEUKOS - Journal of Illuminating Engineering Society of North America*, 6(1): p. 7-35.



## **Study assessing the environmental performance of natural hydraulic lime**

Nagasawa, T<sup>1</sup> ; Nakajima, Y<sup>2</sup>

<sup>1</sup> Graduate School, Kogakuin University, Tokyo, Japan

<sup>2</sup> Associate Professor, Kogakuin University, Tokyo, Japan

**Abstract:** *This study focused on natural hydraulic lime (NHL), a traditional building material used in Europe. NHL is a recyclable natural material that is air-setting and hydraulic (i.e. it sets under water), and it has various environmental capabilities such as absorbing and releasing moisture and absorbing odors. This paper presents an evaluation of the environmental capabilities of NHL specimens. Results revealed that NHL is effective at improving indoor air quality.*

**Keywords:** *Natural Hydraulic Lime, Environment Performance, Moisture Absorption and Release, Absorption Performance*

### **1. Introduction**

Over the past few years, building materials tailored to the environment that improve air quality and control temperature and humidity have garnered attention. Building materials featuring natural material are being reconsidered and interest in these materials has heightened. Thus, the current study focused on natural hydraulic lime (NHL), which is a traditional building material used in Europe. NHL absorbs and releases moisture, it absorbs VOCs, it insulates, it stores heat, and it retains water. NHL has a prescribed strength in Europe, but data on its environmental performance have not been obtained. This study evaluated the environmental performance of building materials made of NHL in order to encourage the development of those materials.

### **2. Overview of NHL**

NHL is defined in European norm EN459-1 as “limes produced by burning of more or less argillaceous or siliceous limestones with reduction to powder by slaking with or without grinding. They have the property of setting and hardening under water. Atmospheric carbon dioxide contributes to the hardening process.” Hydraulic setting of NHL is the result of clayey material contained in limestone. Use of NHL declined with the widespread use of Portland cement. In Japan, building materials for environmental control have garnered attention, but there is little recognition of NHL. Therefore, hydraulic lime has not been used in Japan and there are no previous examples of its use. NHL has recently been reconsidered because of its environmental performance.

### 3. Aspects of environmental performance studied and Overview of specimens

#### 3.1 Aspects of environmental performance studied

This study examined the environmental performance of NHL as an interior finishing material. Specimens of NHL for use as interior finishing materials were compared, depending on their composition, in terms of thermal performance, absorption and release of moisture, and absorption of various gases.

#### 3.2 Overview of specimens

In light of the aspects being studied, specimens for assessment were prepared with different aggregates and compositions. NHL is a plastering material containing aggregate and admixtures. Specimens in Group A had a basic composition of A-2 along with different sizes and amounts of foamed glass (a filler). For comparison, specimens in Group B had a basic composition of B-1 with air-setting lime from limestone or lime from scallop shells (which has the same compositional formula as lime from limestone). Foamed glass, which is a recycled form of waste glass with a low specific gravity, and cellulose fiber, which would presumably control moisture, were chosen as fillers.

Table 1 Types of specimens

Group and specimen no.		Kind of the lime	* Aggregate	Filler	Ratio by weight			Thickness	
					NHL	Aggregate	Filler		
A	A-1	NHL2.0	granite 0.5mm	—	1	3	—	2mm	
	A-2		granite 2mm	foamed glass size-L			0.8	10mm	
	A-3			foamed glass size-M					
	A-4			foamed glass size-S					
	A-5			foamed glass size-M					
	A-6			foamed glass size-M			1.2		
	A-7			foamed glass size-M			0.4		
	A-8			foamed glass size-S		2	0.5		
	A-9			foamed glass size-M					
B	B-1	silica sand size-5	—	1	2	—			
	B-2		cellulose fiber			0.03			
	B-3	lime from limestone	silica sand size-5		—	2		—	
	B-4	lime from scallop shells							
C	C-1	tile building material with reduced VOCs (Ready-made product)							
	C-2	diatomite building material (Ready-made product)							

Table 2 Grain size distribution

	size distribution diameter(mm)
silica sand size-5	0.212–0.85
foamed glass size-L	1–2
foamed glass size-M	0.5–1
foamed glass size-S	0.25–0.5

### 4. Thermal conductivity test

#### 4.1 Test summary

The thermal conductivity of specimens was measured. A quick thermal conductivity meter was used to measure the thermal conductivity of a 250-mm square specimen. This test used a solid panel as a specimen to account for the effects of gypsum board as a substrate.

#### 4.2 Test results

Thermal conductivity results are shown in Fig. 1. Adding foamed glass with a low specific gravity to a specimen with A-2 as its basic composition improved the specimen's thermal conductivity to the extent that it was comparable to the thermal conductivity of gypsum board. The fact that NHL is hydraulic means that it can be applied in a thick coat, so it can be

applied even if it contains foamed glass several mm in size. When the size of the foamed glass particles was changed but the ratio of foamed glass was not changed, thermal conductivity decreased with the addition of large particles of foamed glass.

Table 3 Thermal conductivity

Group and specimen no.		Specific gravity [g/cm <sup>3</sup> ]	Thermal conductivity [W/mK]
Solid panel			
A	A-1		
	A-2	1.497	0.555
	A-3	1.188	0.252
	A-4	1.225	0.351
	A-5	1.278	0.342
	A-6	0.954	0.242
	A-7	1.364	0.358
	A-8	1.144	0.368
	A-9	1.183	0.311
Reference	Gypsum board	0.58	0.213

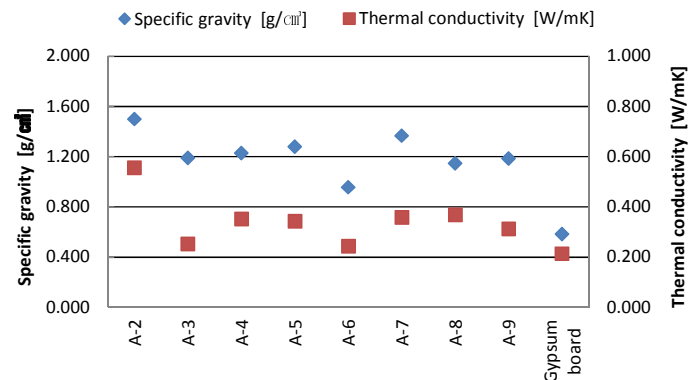


Fig. 1 Chart of the correlation in thermal conductivity

## 5. Humidity control test

### 5.1 Test summary

This test determined the effectiveness of humidity control indoors. Testing was based on an intermediate moisture level as indicated in Japanese Industrial Standards (JIS) A 1470-1, “Determination of water vapor adsorption properties for building materials—Part1: Response to humidity variation.” A specimen in a steady state was subjected to moisture absorption (23°C, 75%, 12 hours) and then moisture desorption (23°C, 50%, 12 hours). Changes in the weight of each specimen were measured each minute using an electronic balance.

### 5.2 Test results

Results are shown in Fig. 2 and Table 3. A-2 contained only NHL and aggregate, and it had better moisture absorption and release than the other specimens in Group A that contained foamed glass. This is because the foamed glass did not facilitate moisture absorption and release as a filler. In addition, foamed glass stands out on the surface, reducing the proportion of the surface via which NHL can absorb moisture. Cellulose fiber was added to specimens in Group B, and this was found to improve moisture absorption and release. Some specimens of NHL met certain standards for moisture

Table 4 Humidity Control

Specimen no.	amount of moisture absorption [g/m <sup>2</sup> ]	amount of moisture release [g/m <sup>2</sup> ]	rate of moisture absorption / release [%]
A-1	20.3	12.5	61.7
A-2	29.5	21.8	73.7
A-3	17.2	16.0	92.8
A-4	21.3	16.8	78.8
A-5	17.3	14.0	81.0
A-6			
A-7	15.3	14.2	93.4
A-8	20.8	19.5	94.0
A-9	21.3	15.3	71.8
B-1	22.0	18.8	85.0
B-2	46.8	26.5	56.7
B-3	17.8	16.3	91.5
B-4	22.0	18.8	85.2

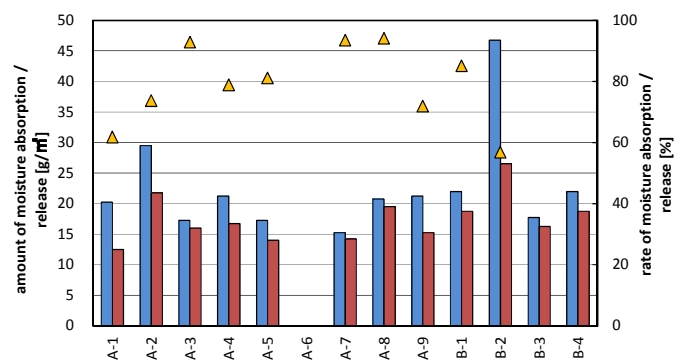


Fig. 2 Comparison of performance in terms of moisture absorption/release

absorption and release by building materials as set forth by the Japan Testing Center for Construction Materials.

## 6. Ammonia absorption test

### 6.1 Test summary

This test used ammonia as an example of an odor source in order to determine how effectively specimens adsorbed odors. This test was based on JIS A 1901, “Determination of the emission of volatile organic compounds and aldehydes for building products—Small chamber method.” Specimens that were 10-cm square were placed in a 20-L bag, and 20 L of air with an odor intensity of 4 (conc: 10 ppm) as specified by the Air Fresheners & Deodorizers Conference was injected into the bag. The ammonia concentration in the bag was measured after 1, 2, and 24 hours. Measurement was done by visually inspecting the detector tube and examining each specimen’s absorption and desorption of ammonia. Afterwards, specimens were placed in a new bag filled with fresh air and then placed in a chamber at 45°C. Air in the bag was sampled, and the amount of ammonia released by each specimen was examined after 1 and 3 hours. In addition to B-1, B-3, and B-4, vinyl wallpaper was also tested for comparison.

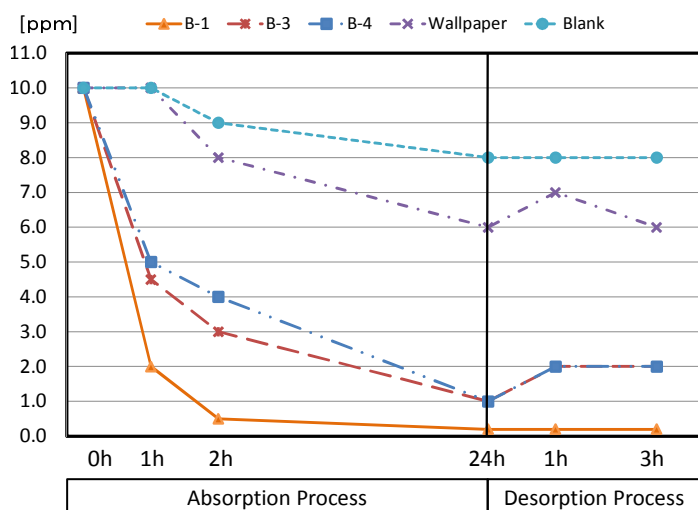


Fig. 3 Changes in the concentration of ammonia

### 6.2 Test results

The concentration of ammonia over time is shown in Fig. 3. Looking specifically at the adsorption process, A-10 had the fastest adsorption rate of all the specimens, and it reduced the ammonia concentration to 2 ppm in 1 hour. B-3 and B-4 took more time than B-1 to adsorb ammonia. Looking specifically at the desorption process, B-1 did not release absorbed ammonia. Therefore, only A-10 completely degraded ammonia.

## 7. Formaldehyde absorption test

### 7.1 Test summary

This test used formaldehyde as an example in order to determine how effectively specimens adsorbed a VOC. Testing was done in the same manner as the Ammonia Absorption Test in 6. Formaldehyde (gas) was added so that the formaldehyde concentration in air would be 0.4 ppm, which is about 5 times the level (0.4 ppm) specified by the Ministry

of Health, Labor, and Welfare (MHLW). In addition to A-10, B-1, and B-2, vinyl wallpaper was also tested for comparison.

7.2 Test results

The concentration of formaldehyde over time is shown in Fig. 3. With specimens A-10, B-1, and B-2, the formaldehyde level reached about 0.08 ppm, the level specified by the MHLW, after 2 hours. In comparison, vinyl fabric absorbed some formaldehyde but released it. Twenty four hours after the desorption process, the formaldehyde level was equivalent to that in the bag of air, so the specimens did little to absorb and degrade formaldehyde. There was little difference between specimens A-10, B-1, and B-2 in terms of the absorption process, but they did reduce the amount of formaldehyde for up to 24 hours.

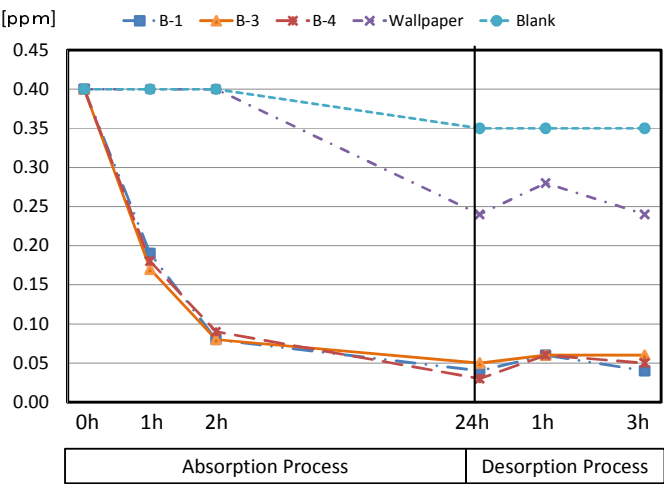


Fig. 4 Changes in the concentration of formaldehyde

8. Mold resistance test

8.1 Test summary

This test was based on JIS Z 2911, “Mold Resistance Testing.” The fungus used was *Cladosporium* sp. *Cladosporium* is a black mold that is often found in houses growing on building materials and in shower stalls. Since growth of mold requires moisture and organic nutrients, each specimen was coated with nutrients to hasten the growth of mold. In addition to specimens A-10, B-1, and B-2, other tested specimens were vinyl wallpaper, gypsum board [GB], wood, and an earthen wall. Specimens were coated with a fungal suspension and then the fungus was cultured for 4-8 weeks in a chamber with a constant temperature and humidity (25°C, 90% RH) to facilitate the growth of mold.

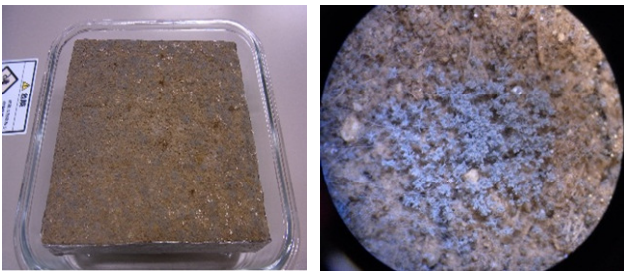


Fig. 5 Surface of the earthen wall after 8 weeks

Table 5 Hypha development assessed in 6 stages

Growth of mold	Assessment of hypha development	specimen no.	Growth of mold
0	Growth of mold is not noted with the naked eye or under a microscope.	B-1	0
		B-3	0
1	Although growth of mold is not noted with the naked eye, it is apparent under a microscope.	B-4	0
		Wallpaper	0
2	Growth of mold is noted with the naked eye, and the area of growth portion is less than 25% of the total surface of the specimen.	Gypsum board	3
		Wood	2
3	Growth of mold is noted with the naked eye, and the area of growth is less than 50% of the total surface of the specimen.	Earthen wall	4
4	Hyphae are well developed and the area of growth is 50% or more of the total surface of the specimen.		
5	Hyphae are highly developed and have covered the entire sample.		



## 8.2 Test results

Results are shown in Fig. 3. After 8 weeks, hypha development was not noted on the surface of Group B specimens or on wallpaper even under a microscope. Hypha development was noted on the surface of wood and the gypsum board. Hypha development was noted on the surface of the earthen wall 3 days after the fungal suspension was applied. After 4 weeks, hyphae had developed on the earthen wall and covered 50% or more of its surface.

## 9. Conclusion

Thermal conductivity testing revealed that adding foamed glass with a low specific gravity to a specimen of NHL with a basic composition improved the specimen's thermal conductivity to the extent that it was comparable to the thermal conductivity of gypsum board. Humidity control testing revealed that specimens of NHL met the criteria for humidity-controlling building materials in Japan. Ammonia absorption testing revealed that NHL did not release absorbed ammonia during the desorption process, and ammonia was completely degraded by NHL specimens. Formaldehyde absorption testing revealed that specimens in Group B reduced the formaldehyde level to 0.08 ppm after 2 hours and to 0.05 ppm after 24 hours. These results indicate that NHL has great potential to serve as a building material for environmental control.

## Acknowledgment

The authors wish to thank Silica Lime Co., Ltd. for the data and materials that the firm provided.

## References

- [1] Osanai, S et al. Investigation of Various Environmental Performances of NHL and Its Utilization, (Part8) Investigation of absorption and desorption of moisture, VOC absorption, fungus resistance by using plasterer test pieces, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan 2012 No. 40531
- [2] Nakamura, S et al. Investigation of various environmental performance of NHL and its utilization, (Part3) Investigation of thermophysical properties by using test pieces, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan 2009 No. 40521
- [3] Nakajima, Y et al. Development of environment controllable building materials using NHL(NATURAL HYDRAULIC LIME), Architectural Institute of Japan Journal of Technology and Design 15(31), 843-847, 2009-10

## **The Effect of Material Service Life on the Life Cycle Embodied Energy of Multi-Unit Residential Buildings**

Rauf, A.<sup>1</sup>; Crawford, R.H.<sup>1</sup>

<sup>1</sup> The University of Melbourne, Faculty of Architecture, Building and Planning, Melbourne, Australia

**Abstract:** *Previous analyses of energy across the various life cycle stages of a building have shown the significance of both the energy required for building operation as well as energy embodied in initial building construction. Service life and durability of materials are among the most important factors affecting the embodied energy associated with maintenance and replacement of materials over a building's life. Variations in service life of materials can potentially lead to significant variability in a building's embodied energy. The aim of this study was to investigate the effect of variations in the service life of materials on the life cycle embodied energy demand associated with a multi-unit residential building. The initial and recurring embodied energy of a case study building were calculated, with material service life values based on average figures obtained from the literature. These values were then varied to reflect the extent of service life variability likely for a selection of the main building materials and the recurring embodied energy recalculated for each scenario. The results from this initial study indicate that the service life of materials can have a significant effect on the total energy embodied in a building over its life.*

**Keywords:** *material service life; recurrent embodied energy; life cycle embodied energy; multi-unit residential building*

### **Introduction**

Fossil fuel-based energy use is considered one of the largest contributors to environmental degradation and global warming. The main source of greenhouse gas (GHG) emissions from the building sector is energy consumption [1]. Buildings are responsible for 30-40% of energy use and associated GHG emissions both in Australia and worldwide with a significant share of this attributable to residential buildings [2]. This problem is further exacerbated with the increasing global population, expected to reach 8 billion by 2028 [3]. It is likely that urban growth and its related infrastructure will continue to impact greatly on the natural environment well into the future, particularly through the consumption of raw materials and energy. In this scenario, it is important for all stakeholders in the building industry to incorporate strategies at the feasibility and design stages of buildings to reduce the energy consumption associated with the building sector in order to reduce greenhouse gas emissions and avoid further degradation of the natural environment.

Previous studies have shown the significance of the energy required for the operation of buildings as well as the energy embodied in initial building construction [4]. Few studies have

analysed the recurrent embodied energy involved in maintenance and refurbishment activities over a building's life [5, 6]. Recurrent embodied energy associated with the replacement of building materials and components is directly affected by the service life of building materials. However, the significance of material service life and recurrent embodied energy on the life cycle energy performance of a building is not well known. The aim of this study was to determine what effect variations to the service life of materials have on the life cycle embodied energy demand associated with multi-unit residential buildings.

## Background

### *Recurrent embodied energy of buildings*

The energy associated with the production of construction materials and construction of a building, known as a building's *initial embodied energy*, has been quantified in numerous previous studies [inter alia 7, 8, 9]. While there is still considerable debate around the appropriate method of analysis that should be used, the principles around how embodied energy is calculated are fairly well understood. However, the quantity of energy associated with manufacturing the materials needed for maintenance and repair throughout a building's life is much less understood. There are a much more limited number of studies where this *recurrent embodied energy* has been calculated. Some of the reasons for this are the considerable variability that exists in the service life of materials and the lack of building material and component service life data. A study by Treloar *et al.* [10] shows that embodied energy associated with the replacement of building materials can represent up to 32% of the initial embodied energy of a building. Another study by Crawford on residential construction assemblies shows that the energy embodied in material replacement can represent between 7 and 110% of their initial embodied energy [5]. In a study of office buildings, Cole and Kernan [11] have also shown that recurrent embodied energy can be significant, representing 1.3, 3.2 and 7.3 times the initial embodied energy value for an assumed building lifespan of 35, 50 and 100 years, respectively. In another study of residential buildings, embodied energy was increased due to the maintenance and replacement of materials from 14.1 GJ/m<sup>2</sup> to 23.5 GJ/m<sup>2</sup> over 50 years and to 35.41 GJ/m<sup>2</sup> over 100 years [12].

### *Service life of building materials*

A material's service life is the amount of time that it can be expected to be serviceable. While predictions of service life will often be based on previous experience or warranty periods, a number of key factors will determine the actual service life of a material in use. These factors include material quality, design and detailing, quality of workmanship, maintenance regime and levels, material durability and exposure to deteriorating effects associated with the local climate and environment [13].

The service life of a material affects the number of times it will be replaced over the life of a building. The lower the service life of a material, the greater the quantity of material required for ongoing maintenance and repair and therefore the greater the embodied energy demand associated with manufacturing and installing replacement materials throughout a building's

life. As it is typically fossil fuel-based, this additional demand for energy may result in a considerable ongoing burden on the environment.

### Case study building

In Australia, medium density housing is the most rapidly growing dwelling type. Flats and apartments accounted for 11% of all dwellings in 2009-2010 [14]. A nine-storey apartment building, known as Forte, located in Melbourne, Australia and constructed by Lend Lease in 2012 was used as the case study for this analysis (Figure 1). This building is currently the world's tallest timber building with 197 m<sup>2</sup> of retail space on the ground floor and 23 residential apartments with a total area of 1,558 m<sup>2</sup> [15]. Concrete is used for the footings and ground floor. From the first level up, the entire structure (including load bearing walls, floor slabs, stairwells and elevator cores) is composed from solid timber using Cross Laminated Timber (CLT). A 10 mm thick layer of Uniroll (manufactured using recycled foam rubber and cork) was applied to all CLT flooring [15]. External walls are clad with an additional protective rain screen made of a 4 mm thick LDPE core with two aluminium sheets of 0.5 mm thickness on either side of this core. The windows are double-glazed and aluminium-framed.



Figure 1 Exterior (left) and interior view (right) of Forte building. Source: ANCR [16]

### Life cycle embodied energy analysis

In order to determine what effect a variation in the service life of materials would have on the life cycle embodied energy demand of the case study building, it was necessary to quantify the building's total life cycle embodied energy including its initial and recurring embodied energy. A range of scenarios for the service life of some of the main construction materials were then developed and the life cycle embodied energy demand of the building recalculated.

#### Initial embodied energy

An input-output-based hybrid analysis was used to quantify the embodied energy associated with the initial construction of the case study building. Delivered quantities of materials used in the construction of the apartment building were multiplied by the embodied energy coefficient of the respective material, obtained from Treloar and Crawford (2010). Any



remaining data gaps were filled with the use of a disaggregated energy-based input-output model of the Australian economy. This accounted for non-material inputs required in the construction of the building (e.g. services). A detailed description of the hybrid approach used is provided by Crawford [17].

#### *Recurrent embodied energy*

The recurrent embodied energy was calculated based on the number of times each individual material would likely be replaced during the useful life of the building. Average material service life figures from the literature were assumed for this initial analysis (see [6]). The period of analysis chosen for this study was 50 years and thus it was assumed at the end of this period the building would be at the end of its useful life, and demolished.

The embodied energy associated with the materials being replaced over the life of the building was calculated as per its initial embodied energy. The delivered material quantities associated with each replacement were multiplied by the material embodied energy coefficients. Input-output data was then used to fill any remaining data gaps as for initial embodied energy. The energy embodied in each material was then multiplied by the number of replacements for that material over the life of the building, and summed to determine the total recurrent embodied. The exact number of replacements required for each material was determined by dividing the service life of the building (50 years), by the average service life of the material, subtracting 1 (representing the material used in initial construction at Year Zero) and rounding up to the nearest whole number (to reflect the fact that materials can only be replaced in whole numbers).

#### **Material service life scenarios**

The average material service life values used in the initial analysis of the recurrent embodied energy of the building were varied to determine the effect of material service life on its total life cycle embodied energy demand. The material service life scenarios were chosen to reflect the extent of service life variability likely for a selection of the main building materials used within the building. The life cycle embodied energy demand associated with the building was then recalculated for each scenario. Initial embodied energy was constant across each scenario as this is not affected by variations to the service life of the materials. Changes to the service life of materials will affect the recurrent embodied energy demand, however.

Minimum and maximum material service life values from the available literature were used as the basis of the two different material service life scenarios chosen for the main construction materials (i.e., timber, concrete, steel, carpet, paint etc.). A list of specific material service life values used is provided in another study by the authors (see [6]). A limitation of this initial study is that it assumes that for each scenario, all selected materials will be replaced within their minimum, average or maximum service life. In reality this is unlikely, as some materials may be maintained more frequently than others and so may need replacing closer to their maximum service life while others, which may not have been subject to more frequent maintenance, may need to be replaced closer to what might be considered their minimum



service life. The purpose of this study is thus to determine the possible extremes in variability of life cycle embodied energy that may be attributed to variations in the service life of materials.

## Results and Discussion

This section presents the results of the analysis including the initial and recurrent embodied energy associated with each material service life scenario for the case study building.

### *Initial embodied energy*

The embodied energy calculated for the initial construction of the case study building was found to be 105,832 GJ (60 GJ/m<sup>2</sup>). CLT panels were found responsible for the highest amount of initial embodied energy (35%) followed by steel and concrete with a share of 21% and 13%, respectively.

### *Recurrent embodied energy*

The recurrent embodied energy associated with the replacement of materials for the building over a period of 50 years, based on average service life figures obtained from the literature, was found to be 46,985 GJ (27 GJ/m<sup>2</sup>). For the minimum and maximum material service life scenarios, recurrent embodied energy was found to be 111,692 GJ (64 GJ/m<sup>2</sup>) and 26,683 GJ (15 GJ/m<sup>2</sup>), respectively. These results reflect the fact that at an increase in material service life will result in a decrease in recurrent embodied energy requirements, up to 76% in the case of the building analysed.

### *Life cycle embodied energy*

Life cycle embodied energy demand for the building over 50 years was calculated by combining initial and recurring embodied energy for each scenario. Based on the average material service life figures, life cycle embodied energy was 152,817 GJ or 87 GJ/m<sup>2</sup>. For the minimum and maximum material service life scenarios life cycle embodied energy was 217,523 GJ and 132,515 GJ, respectively. Figure 2 shows the breakdown of the embodied energy demand by life cycle stage for each material service life scenario. Variations in material service life and thus recurrent embodied energy, results in up to a 39% reduction in life cycle embodied energy demand comparing minimum and maximum material service life results. Compared to the average material service life scenario, the total possible reduction in life cycle embodied energy demand by extending the service life of materials is up to 13%.

As Figure 3 shows, the initial embodied energy of the building represents 49%, 69% and 80% of its life cycle embodied energy demand, for minimum, average and maximum material service life scenarios, respectively. This shows that when materials are poorly maintained and/or require greater frequency of replacement, the recurrent embodied energy of a building may become as significant as the embodied energy associated with its initial construction. This proportion will increase even further for a building with a service life longer than 50 years.

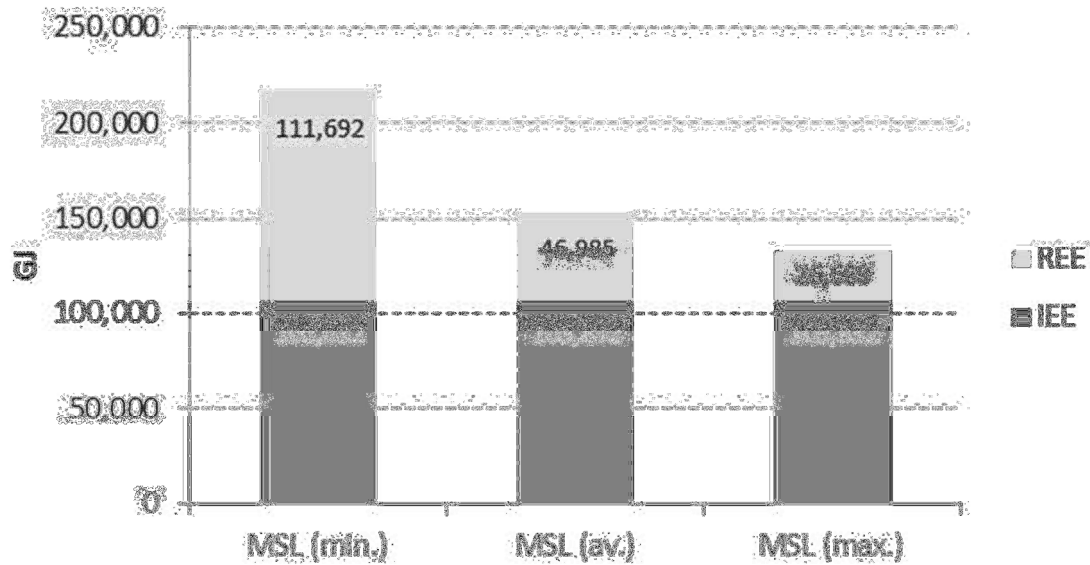


Figure 2 Life cycle embodied energy of the case study building based on minimum, average and maximum material service life scenarios

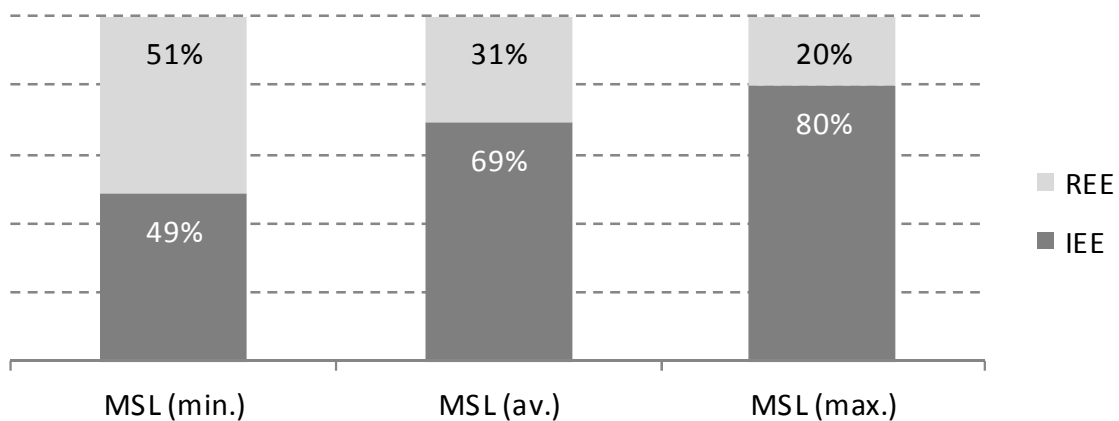


Figure 3 Life cycle embodied energy of the case study building based on minimum, average and maximum service life scenarios, by life cycle stage proportion

## Conclusion

The aim of this study was to determine what effect a variation in the service life of materials would have on the life cycle embodied energy of a multi-unit residential building. A case study apartment building located in Melbourne, Australia was used for this analysis. The initial and recurring embodied energy of the case study building were calculated using a comprehensive hybrid assessment approach, with material service life values based on average figures obtained from the literature. These service life values were then varied to reflect the extent of service life variability (minimum and maximum) likely for a selection of the main building materials and the recurring embodied energy and life cycle energy recalculated for each scenario.



The study has shown that a variation in the service life of materials can significantly affect the recurrent embodied energy of a building. While an increase in the service life of materials was shown to result in a reduction in recurrent embodied energy demand of up to 76% for the apartment building analysed, in terms of the total life cycle embodied energy demand of the building, the reduction was found to be in the order of up to 39%.

This study has also shown that the recurrent embodied energy associated with the maintenance and replacement of materials can be significant. In fact, the recurrent embodied energy requirement for material replacement may be as significant as the initial embodied energy of a building over 50 years and likely to be more significant for buildings with a service life beyond this. This demonstrates that in an attempt to reduce the life cycle energy demand of buildings and minimise the associated environmental impacts, it is important that the service life and durability of materials is taken into account. This also suggests that the use of more durable materials may be a preferred option. However, as more durable materials may be more energy intensive in some cases, the service life of buildings should be considered when specifying these types of materials to ensure any unnecessary energy demand associated with over specification is avoided. Consideration of material choice in the context of a building's thermal performance is also important so that the selection of materials to minimise embodied energy across the building life cycle does not adversely affect a building's thermal performance and thus operational energy demand.

## References

1. UNEP (2009) *Buildings and Climate Change - A Summary for Decision-makers*, United Nations Environment Programme: France.
2. UNEP (2007) *Buildings & Climate Change: status, challenges & opportunities*, United Nations Environment Programme.
3. UN (1999) *The World at Six Billion*, United Nations Population Division: New York, USA.
4. Treloar, G.J., Love, P.E.D., and Holt, G.D. (2001) *Using national input-output data for embodied energy analysis of individual residential buildings*. Construction Management & Economics. **19**(1): p. 49-61.
5. Crawford, R.H., Czerniakowski, I., and Fuller, R. (2010) *A comprehensive framework for assessing the life-cycle energy of building construction assemblies*. Architectural science review. **53**(3): p. 288.
6. Rauf, A. and Crawford, R.H. (2013) *The relationship between material service life and the life cycle energy of contemporary residential buildings in Australia*. Architectural Science Review. **56**(3): p. 252-261.
7. Treloar, G.J. (1998) *A Comprehensive Embodied Energy Analysis Framework*, in *Faculty of Science and Technology* Deakin University: Geelong.
8. Crawford, R.H. (2004) *Using Input-Output Data in Life Cycle Inventory Analysis*, Deakin University: Geelong.
9. Fay, M.R. (1999) *Comparative Life Cycle Energy Studies of Typical Australian Suburban Dwellings*, The University of Melbourne: Melbourne.
10. Treloar, G.J., Fay, R., Love, P.E.D., and Iyer-Raniga, U. (2000) *Analysing the life-cycle energy of an Australian residential building and its householders*. Building Research and Information. **28**(3): p. 184-195.



11. Cole, R.J. and Kernan, P.C. (1996) *Life-cycle energy use in office buildings*. Building and Environment. **31**(4): p. 307-317.
12. Fay, R., Treloar, G., and Iyer-Raniga, U. (2000) *Life-cycle energy analysis of buildings: a case study*. Building Research & Information. **28**(1): p. 31-41.
13. ABCB (2006) *Durability in Buildings-Guideline Document*, The Australian Building Codes Board (ABCB): Canberra, ACT.
14. ABS (2012) *Housing -Year Book Australia, 2012*, Cat. No. 1301.0, Australian Bureau of Statistics, Canberra
15. Durlinger, B., Crossin, D.E., and Wong, D.J.P. (2013) *Life Cycle Assessment of a cross laminated timber building* Forest & Wood Products Australia: Melbourne, Victoria.
16. ANCR (2012) *Forte Building*, in [http://www.ancr.com.au/forte\\_apartments.pdf](http://www.ancr.com.au/forte_apartments.pdf) Australian National Construction Review: Victoria, Australia.
17. Crawford, R.H. (2011) *Life Cycle Assessment in the Built Environment*: Routledge-Taylor & Francis.

## Sustainable Insulation Solutions: A lifecycle perspective from Cradle to Cradle. Tools for implementation

### Speakers:

Bermejo Presa, Nicolás<sup>1</sup>

<sup>1</sup> SAINT-GOBAIN ISOVER, Madrid, Spain

**Abstract Summary:** *The world is changing at a faster rate than ever before. Whilst advances in science and technology have improved our quality of life, they have also highlighted how balanced is our environment.*

*To address these issues we must change the way we design new buildings and renovate existing buildings so that we reduce their negative impacts on the environment. The construction process must preserve unique ecosystems, biodiversity and local landscapes, whilst ensuring a better quality of life and guaranteeing the health and safety of building occupants and users. Sustainable construction provides solutions that balance these sometimes contradictory issues and objectives.*

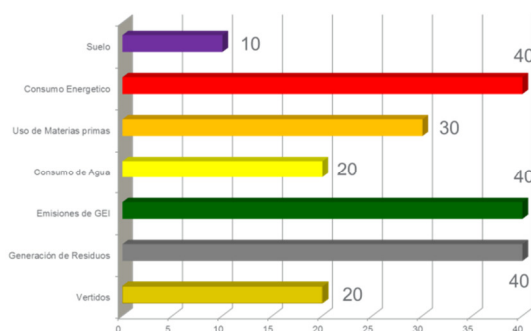
*In this presentation, it is showing the real tools for implementation of this system include:*

- *Interpretation legal requirements to include in EPD*
- *Different Eco Labels*
- *The different stages of the building Life Cycle*
- *Structure of a EPD for a Insulation Products*

**EPD, environmental Product Declaration, lifecycle, LCA, Life Cycle Assessment, Insulation, Glass wool, Stone wool, ISOVER,**

### Impacts in Buildings and Certifications

In developed countries, buildings account for a significant part of resource consumption, greenhouse gas emissions, and waste generation. Building sustainably has certainly become a key requirement for contractors and architects. Regulations and eco labels are pushing for more sustainable solutions in construction. Insulating buildings is the most cost effective way to reduce their energy consumption and CO<sub>2</sub> emissions. Up to 90% of the energy used for heating or cooling can be saved, with no need for maintenance.



using data from UNEP SBCI, 2006.

Figure 1: Word Building Impacts (%). Source Earth Trends, 2007



But .....what is it a green building? Is it possible to measurement the sustainability concept in a building? In fact there are some tools allowing us to measure this concept throw buildings certifications and products certifications (ecolabels):



Figure 2: different building certifications and products certifications

### Eco labels

There are three types of labels (defined by the ISO 14020 standard). Their reliability varies:

- type I labels are environmental or health mono or multicriteria, issued by third party, private or public entities, and are subject to variable levels of verification.
- type II labels are non verified self-declarations.
- type III labels are based on life cycle analysis (LCV) performed according to international standards and so verified by an independent third party.

Life Cycle Assessments are the most reliable techniques to evaluate the environmental impact of construction solutions and buildings:

#### 1. A rigorous scientific approach

LCA is made of rigorous and scientific calculations, using dedicated software and data collected directly from the processes.

#### 2. An exhaustive environmental assessment methodology

LCA is the most comprehensive level of environmental assessment covering all stages in the product life cycle and all environmental impacts.

### 3. An essential tool for eco-innovation

The results of the LCA enable the R&D team to work on improving the current product portfolio, and develop new innovative products with lower environmental impact. This is called ecoinnovation.

### 4. The only tool to avoid impact shifting

Using LCA enables in particular design teams to avoid impact shifting when developing new products.

The European Standard governing this, are following:

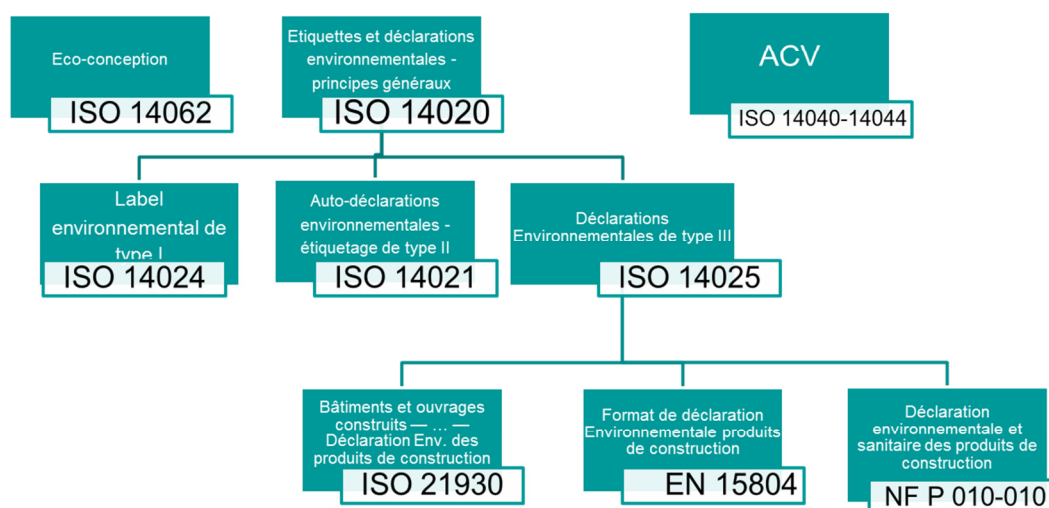


Figure 3: different European standards relationships with life cycle assessments

### The different stages of the building Life Cycle

A LCA assess the consumption of natural resources, energy and water, emissions and releases into the air, ground and water, and waste generation.

The impacts are calculated at each stage of the building life, « from cradle to grave », from the extraction of raw materials, the manufacturing of the products, to their end of life, following deconstruction or demolition of the building.

A LCA means a Life Cycle Assessment. It is considered the state of the art methodology for assessing all relevant environmental impacts of a construction product, of a system or of a building over its entire life cycle. Following international standards (EN 15804 and ISO 21930), a LCA calculates in a rigorous and scientific manner the use of energy, water and natural resources, the emissions and releases into the air, ground and water, and the waste generation. These inputs and outputs are calculated at each stage of the building life cycle.

The building Life Cycle starts at the product stage: raw materials are extracted and processed, secondary raw materials are selected; everything is transported to a plant where the products will be manufactured. During the construction stage, building products are transported from the manufacturing plant to the distributors and to the building site, and installed into the building. Once construction is complete, the use stage begins, including the maintenance, repair or replacement of the installed products. At the end-of-life stage, the building is either deconstructed or demolished; its components are processed for reuse, recovery, recycling or disposal as waste.

According to EN 15 804 standards, there are different stages that must be taking into account:



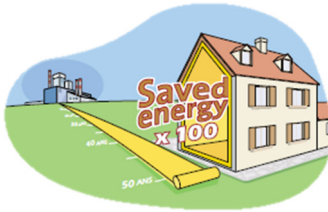

PRODUCTION (Modules A1-A3)	CONSTRUCTION (Modules A4-A5)	USE (Modules B1-B7)	END OF LIFE (Modules C1-C4)
			
<i>From raw material extraction to finished product</i>	<i>From the plant to the construction site</i>	<i>Building Use during 50 years</i>	<i>Building end of life Demolition and recycling</i>
A1: Raw Materials A2: Transport A3: Manufacture	A4: Transport A5: Construction installation process	B1: Use B2: Maintenance B3: Repair B4: Replacement B5: Refurbishment B6: Operational energy use B7: Operational water use	C1: Deconstruction C2: Transport C3: Waste processing C4: Disposal

Figure 4: stages according to EN 15804 Standard must be taking into account in a EPD

The PRODUCTION stage of the mineral wool products is subdivided into 3 modules A1, A2 and A3 respectively “Raw material supply”, “transport” and “manufacturing”.

The Raw material supply module takes into account the extraction and processing of all raw materials and energy which occur upstream to the studied manufacturing process. The transport to the manufacturer raw materials are transported to the manufacturing site. The modeling include: road transportations (average values) of each raw material. Manufacture module includes manufacturing of products and manufacturing of packaging.

The CONSTRUCTION stage is divided into 2 modules: transport to the building site A4 and installation A5. A4, Transport to the building site includes transport from the production gate to the building site. A5, Installation in the building: This module includes: Wastage of products, Additional production processes to compensate for the loss and Processing of packaging wastes.

USE stage: Once installation is complete, no actions or technical operations are required during the use stages until the end of life stage. Therefore mineral wool insulation products have no impact (excluding potential energy savings) on this stage.

END OF LIFE stage includes the deconstruction and/or dismantling of insulation products take part of the demolition of the entire building transport to waste processing, waste processing for reuse, recovery and/or recycling and disposal.

### **Structure of a EPD for a Insulation Products. External Verification**

The verification covers the following main areas:

- The underlying data collected and used for the LCA calculations,
- The way the LCA-based calculations have been carried out to comply with the calculation rules described in the reference PCR,
- The presentation of environmental performance included in the EPD
- Other additional environmental information included in the declaration, if existent
- Robustness of results

The EPD in compliance with the EN 15.804 and ISO 14.025 standards, the next information should be included:

- The name and direction of the manufacturer
- Description of the intended use and the functional unit. The declared functional unit is one m2 and makes reference to its isolation capacity (thermal resistance)
- Clear product identification including name, model and main characteristics.
- Description of the material contents. The material content of the product should be expressed in a qualitative manner, and not in a quantitative one.
- Name and main information of the EPD program operator.
- Date of issue of the EPD and validity of 5 years
- Information about the life cycle stages of the system included in the EPD: including all the life cycle stages as expressed in EN 15.804 standard.



Figure 5: EPD Example

- A declaration where is said that EPDs not following UNE-EN 15.804 are not comparable.
- Reference to relevant websites for more information.
- Information about the verification process
- Environmental impact indicators: as stated in UNE-EN 15.804
- Indicators of use of resources: as stated in UNE-EN 15.804
- Other environmental information describing the different wastes and output flows

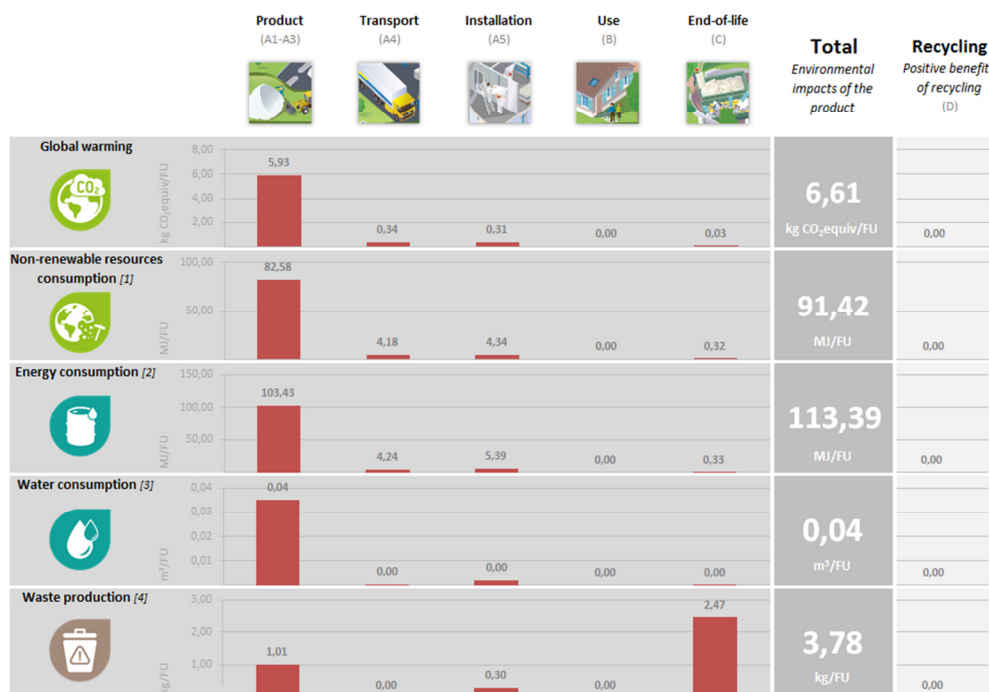


Figure 6: EPD Example final data

## Comunication platfforms

In order to guaranteed the right way to communication, platform as “Plataforma de materiales” from GBCE Spain, allowed lock for products with EPD.

It is a platform that allows architects, builders and developers, meet the environmental characteristics of materials, products and systems and how they contribute to obtaining LEED and GREEN credits certifications.





## Conclusion

In developed countries, buildings account for a significant part of resource consumption, greenhouse gas emissions, and waste generation. Building sustainably has certainly become a key requirement for contractors and architects. Regulations and eco labels are pushing for more sustainable solutions in construction. Insulating buildings is the most cost effective way to reduce their energy consumption and CO2 emissions. Up to 90% of the energy used for heating or cooling can be saved, with no need for maintenance.

The impacts are calculated at each stage of the building life, « from cradle to grave », from the extraction of raw materials, the manufacturing of the products, to their end of life, following deconstruction or demolition of the building.

A LCA means a Life Cycle Assessment. It is considered the state of the art methodology for assessing all relevant environmental impacts of a construction product, of a system or of a building over its entire life cycle. Following international standards (EN 15804 and ISO 21930), a LCA calculates in a rigorous and scientific manner the use of energy, water and natural resources, the emissions and releases into the air, ground and water, and the waste generation. These inputs and outputs are calculated at each stage of the building life cycle.

## References

- ISOVER. (2013).: “Aislamiento Sostenible. Manual de declaraciones ambientales de producto”.
- AENOR (2013).: “Sostenibilidad en la construcción. Declaraciones ambientales de producto. Reglas de categoría de productos básicas para productos de construcción”. UNE-EN 15804.
- ISOVER. (2012).: “Catálogo de Elementos constructivos ISOVER: Obra nueva y Rehabilitación.”.
- AENOR (2006).: “Gestión ambiental. Análisis de ciclo de vida. Requisitos y directrices.”. UNE-EN ISO 14044.



## **Life Cycle Assessment within BNB<sup>1</sup> – Online-Tool eLCA and materials database ÖKOBAU.DAT**

### **Authors:**

Brockmann, T.<sup>1</sup>; Kusche, O.<sup>2</sup>; Rössig, S.<sup>1</sup>

<sup>1</sup> Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), Berlin, Germany

<sup>2</sup> Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany, Institute of Applied Computer Science

**Abstract:** *Life Cycle Assessment (LCA) is an instrument for the evaluation of environmental quality of buildings. Based on specific data from environmental product declarations (EPD) or from the ÖKOBAU.DAT under consideration of the life-cycle phases, a quantified assessment of buildings is possible.*

*To unify and simplify this process of creating LCAs, the online tool eLCA was developed. eLCA is a flexible and modular online tool which enables the creation of LCAs for buildings based on templates of construction elements and materials.*

*Both, ÖKOBAU.DAT and eLCA are initiated and maintained by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), a research Institution under the portfolio of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB).*

***Sustainability, Building Materials, Life Cycle Assessment, Tools, ÖKOBAU.DAT***

### **Introduction**

There are numerous political initiatives - at global, European and national levels - that formulate political objectives in connection with sustainability, such as energy efficiency, resource efficiency and reduction of greenhouse gases. Frequently, the topics relevant to construction are linked to requirements with respect to building materials and building products.

In applying the BNB, many of the sustainability aspects mentioned in the various political initiatives are taken into account by means of the comprehensive sustainability criteria, such as the deconstruction of buildings, recyclability of building products, global environmental effects with the global warming potential at their core, environmental and health-relevant effects on soil, water and air, indoor air quality and other aspects [1].

---

<sup>1</sup> BNB – German assessment system for sustainable construction for federal buildings

BNB is part of the National Sustainability Strategy. With the binding implementation of BNB to new constructions, Germany is pioneering the implementation of certifications schemes for Sustainable Buildings in Europe. It is one of the few countries where the State requires a binding sustainability assessment for its federal construction projects. Most European Countries use such certification systems only on a voluntary basis, if at all.

As the sustainability of a building under the BNB principles is ensured by taking into account all sustainability criteria in relation to Ecological, Economic, Socio-Cultural, Technical and Process Quality, building products are not assessed as individual products, but looked at within the context of the entire building (*Fig. 1*).

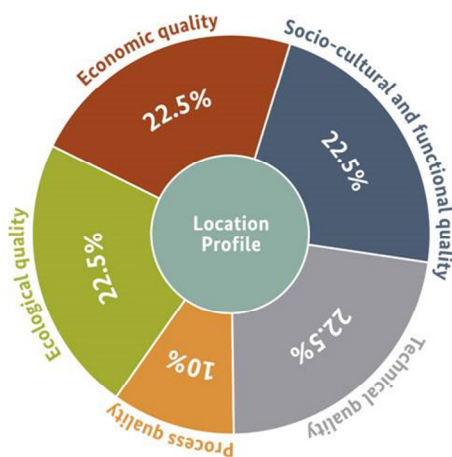


Figure 1: Considered dimensions of sustainability within BNB [2]

Particularly with respect to Ecological Quality, that is, when considering the impact on the global and local environment, building materials form an essential part of the overall assessment. The effects on the global and local environment play a vital role (global warming, ozone depletion, photochemical ozone creation, acidification and eutrophication potential), which are determined by a life cycle analysis, taking into account the life cycle over the chosen time period of 50 years.

As part of the Sustainable Building programme, the federal government provides important aids for choosing suitable building products. ÖKOBAU.DAT supplies basic data for life cycle analyses at building level with the online-tool eLCA.

### Lify Cycle Assessment in BNB

BNB altogether comprises 45 different sustainability criteria profiles. There, 7 out 11 are relatetd to Ecological Quality and 7 of them are covered by LCA on building level (i.e. 1.1.1 "Global Warming Potential", 1.1.2 "Ozone Depletion Potential", 1.1.3 "Photochemical Ozone Creation Potential", 1.1.4 "Acidification Potential", 1.1.5 "Eutrophication Potential", and 1.2.1 "Primary Engergy Demand, non renewable", 1.2.2 "Primary Engergy Demand, renewable").



The LCA within BNB takes into account the phases of building construction, use and disposal. For all of these phases the database ÖKOBAU.DAT supplies necessary data on the building materials and products used in the building.

For the phase of **construction**, all materials used in the building are listed by cost groups 300 and 400 according to DIN 276 [3]. They must then be quantified and included in the life cycle analysis.

The **use** phase includes consideration of building services and systems engineering, such as energy and water supply. In addition, planned repairs must be considered in the use phase. A listing of service lives of materials/products which is provided by the federal government via the information portal indicates the construction elements that will have to be replaced within the considered period of 50 years. These must be recognised in the life cycle assessment, including the materials to be used.

As for the **disposal** phase, generally one must differentiate between the disposal and/or recycling possibilities of recycling, thermal recycling and landfilling.

All these data are factored into the life cycle assessment at building level. Life cycle assessments are generally carried out by experts by means of appropriate software tools, such as e.g. eLCA. Frequently, these tools generate additional data for relevant life cycle costs (relevant to criteria profile 2.1.1 "Building-related Life Cycle Costs"). At the end, the building-specific values of the environmental factors are supplied that result, depending on the extent of requirements, in the assessment of the corresponding criteria profile. The objective is to select the materials for a positive assessment in such a way that the negative contributions to environmental impact remain as low as possible.

### ÖKOBAU.DAT

ÖKOBAU.DAT is a database of life cycle assessment (LCA) data sets for generic and specific construction materials and components. ÖKOBAU.DAT is offered as online database on the newly developed webpage [www.oekobaudat.de](http://www.oekobaudat.de).

ÖKOBAU.DAT contains generic basic data sets that provide suitable averages of the environmental indicators for the building materials, as well as product-specific data sets that are determined for environmental product declarations (EPD). Using the generic data sets allows sustainability studies of buildings already in early planning stages when architects or planners do not yet work with product specific but with generic building product information. In a later stage, the generic data in the model is then substituted by specific data representing actual construction products.

When the first version of the ÖKOBAU.DAT was provided (by PE International AG within a research project of BMUB), there was neither a commonly accepted standard defining the specific calculation rules for EPDs nor a technical data format available to store the LCA results.

Only since EN 15804 [4] was written to introduce more rigorous rules for the building sector in how to set up the environmental models of the life cycle products and calculate comparable environmental life cycle indicators, more EPD program holders implemented EN 15804 into their specific programs. The German IBU scheme from the Institute for Construction and Environment e.V. (IBU), which significantly contributes product specific data sets for the ÖKOBAU.DAT, was the first to introduce the new standard in their EPD program rules.

Hence, a BMUB research project was initiated to develop a data format which meets current European standardization processes and carried out by KIT (Karlsruhe Institute of Technology, Institute for Applied Computer Science). As a result, ÖKOBAU.DAT follows the European Standard EN 15804 since September 2013. In new versions of ÖKOBAU.DAT only data are accepted that follow this standard. For example, the modular approach with life cycle modules (A1-A3, B1 to B6, C1 to C4, and D) as well as required environmental indicators (24 parameters) according to EN 15804 has to be regarded. The ÖKOBAU.DAT therefore is the first database which comprehensively offers life cycle data meeting European Standard EN 15804.

### Webpage

ÖKOBAU.DAT is presented in a newly developed webpage which offers a userfriendly access to the database. For example, basis information as well as interesting links is given, different versions of the ÖKOBAU.DAT are archived (*Fig. 2*).

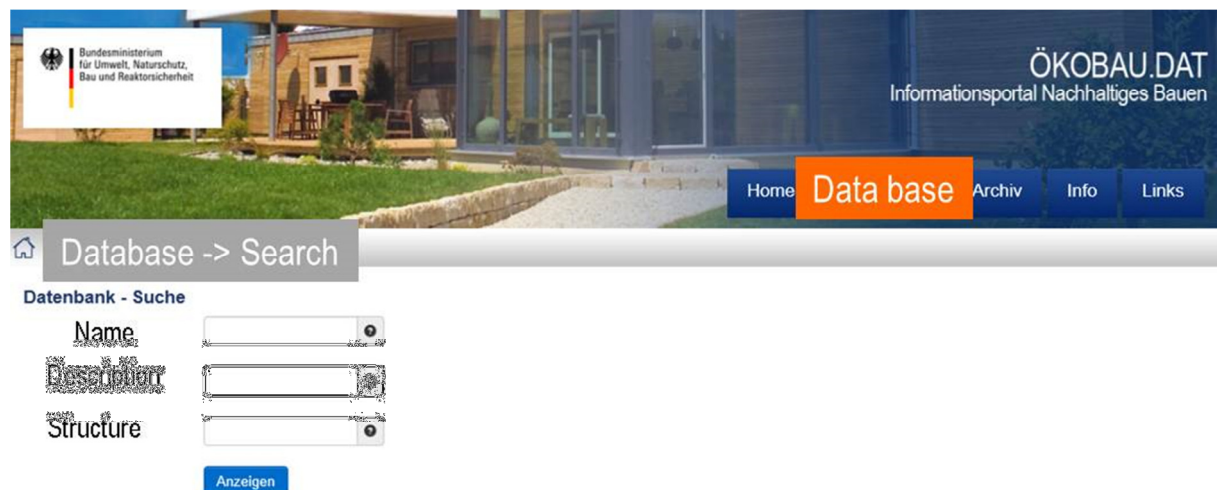


Figure 2: Screenshot of [www.oekobaudat.de](http://www.oekobaudat.de) – search functionality in German online data base ÖKOBAU.DAT

In the past, the data had to be downloaded as a single comprehensive zip.file. Hence, it is an important innovation that now, there is given direct access to the online-database. Search- and filter- functionalities allow finding relevant datasheets for chosen materials or products directly in the online database. *Fig. 3* shows a detail of a datasheet of the ÖKOBAU.DAT: here modules A1-A3, A5, C3, C4, D conforming to EN 15804 for different environmental indicators. The datasheets furthermore include information on the raw materials production and production processes used in the manufacture of the product, e. g. cradle-to-gate.



Indikator ↕	Einheit ↕	A1-A3	A5	C3	C4	D
ADP,E	kg Sb-Äqv.	0.0009389	4.667E-9	5.211E-10	2.133E-7	-1.372E-7
ODP	kg R11-Äqv.	2.839E-8	3.694E-11	2.1E-12	5.4E-10	6.833E-12
AP	kg SO <sub>2</sub> -Äqv.	0.03972	0.00005444	0.000005356	0.003667	-0.01228
EP	kg Phosphat-Äqv.	0.005367	0.00001067	0.000001133	0.0006611	-0.001
GWP	kg CO <sub>2</sub> -Äqv.	21.26	0.5056	0.1	2.994	-3.5
ADP,F	MJ	313	0.1444	0.01111	7.978	-42.21
POCP	kg Ethen-Äqv.	0.004867	0.000003406	6.333E-7	0.001044	-0.001839

Figure 3: Data sheet (details) in online database ÖKOBAU.DAT according to modules of EN 15804

### Online database

Due to the new organization as an online database, ÖKOBAU.DAT does not only show helpful applications on the user surface, it furthermore allows the online import and export of data for all interested stakeholders.

In consequence of the EN 15804 standard, the EPD data format employed by the ÖKOBAU.DAT was revised, as described above [5]. Furthermore, the online data base follows an extended ILCD data format, which originally has been specified by the European Commission and implemented by KIT as an XML data exchange format to exchange LCA data (EU COM 2011). As an Internet aware data format, it has been designed to explicitly allow publishing and linking of data as resources over the Internet. Within the project, an extended data format based on ILCD for modelling EPD data was developed. The advantage of this new approach is that existing software tools with built-in support for the ILCD format can be easily enabled to support the new EPD dataset as well, with only minor changes to their internal information structures. It is to emphasize that ÖKOBAU.DAT is running on an open source programme software platform (soda4LCA), which allows the development of further modules which use or can add new features to the ÖKOBAU.DAT. The integrated tool chain for online data exchange is organized as shown in Fig. 4.

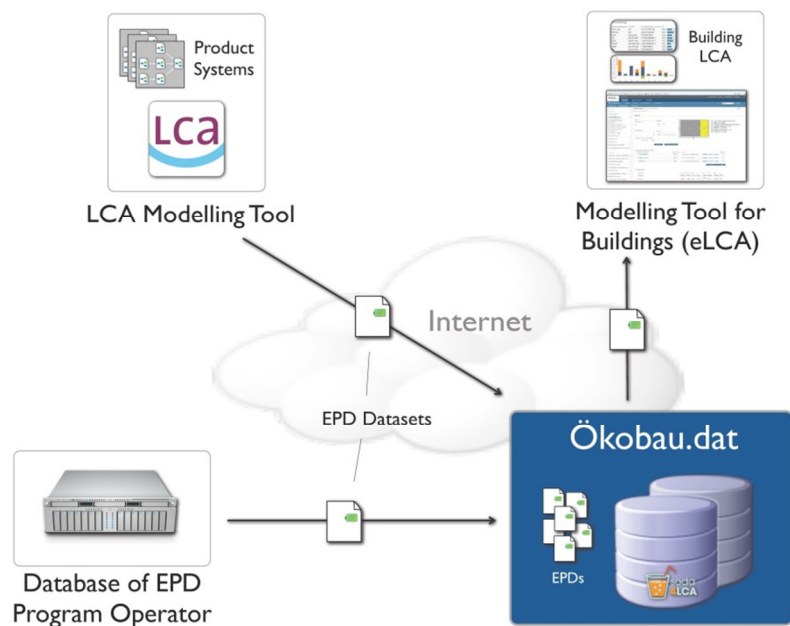


Figure 4: Tool chain for online data exchange with ÖKOBau.DAT (figure by Oliver Kusche, KIT)

Data from EPD program holders can easily be imported in the online data base. For example, in Germany, IBU as an important EPD program holder is working to equip its own database application with facilities to directly import its data online into ÖKOBau.DAT. As not all institutions which may offer suitable building materials related data will be able to generate data with an tool of their own, a further research project has been set up to modify the widely-adopted open source LCA modelling tool “openLCA” accordingly to allow creating suitable EPD data which subsequently can be imported into ÖKOBau.DAT, even online directly from openLCA (Fig. 4).

### eLCA

However, ÖKOBau.DAT delivers life cycle assessment data of building products that are factored into the life cycle assessment at the building level. Consequently, a further BMUB research project was initiated with main purpose to develop a BNB compliant LCA tool for buildings. eLCA was developed within a BMUB research project by BEIBOB Medienfreunde, Germany. eLCA is an open source online tool, which is available free of charge via [www.bauteileditor.de](http://www.bauteileditor.de). The underlying data is based on the building materials database ÖKOBau.DAT. The structure of the online eLCA tool is organized in three levels.

In "building materials" all information and environmental parameters from the ÖKOBau.DAT are stored. The online data base ÖKOBau.DAT allows an export of its data to eLCA. All versions of ÖKOBau.DAT can be chosen within eLCA.

In "templates of construction elements" public templates of typical building components and construction elements are given, e. g. a sandwich panel as a component and an external wall as a construction element. These templates are helpful, as in general within a project,

components or construction elements will be used frequently when data input for specific building models has to be carried out.

In “projects”, in addition to the public templates of construction elements, the user can create private, project-specific components and construction elements. Within the project level, the data input is based on the project specific building models. The building structure is created by the components and construction elements with the associated materials. The underlying data of materials is given in the ÖKOBAU.DAT – in eLCA the contribution of all materials to the environment (indicators 1.1.1 to 1.2.1, global warming potential etc., see above) has to be calculated in the amount of the materials as used in the real construction, following the structure of German Standard DIN 276. A specific feature of eLCA is that the creation of elements is associated with dynamic graphs which show the thickness of different material layers – this helps to prove the created building components and elements (Fig. 5).

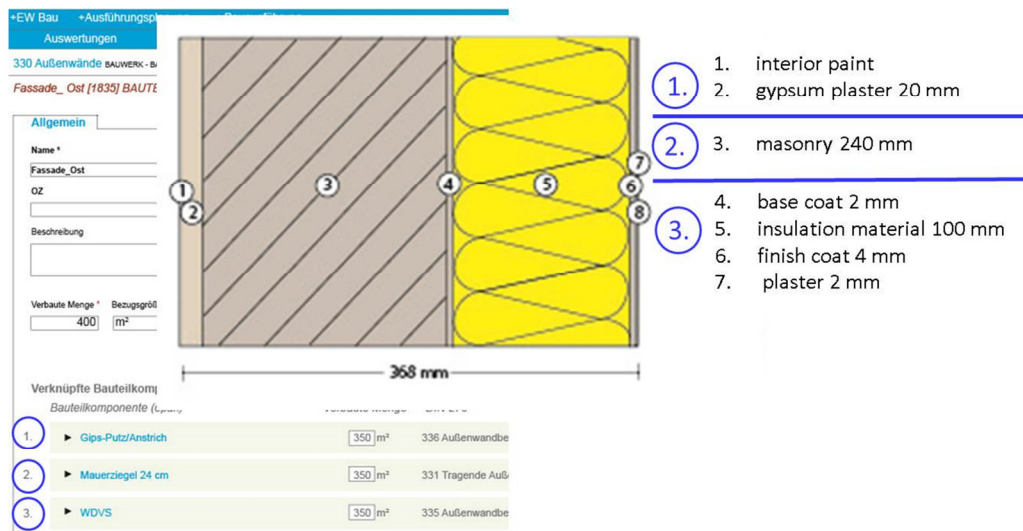


Figure 5: eLCA - Dynamic graph of building component

The product and construction stage, use stage, and end of life stage are considered within eLCA. The evaluation of the project's life cycle assessment can be presented as a total score result, which is relevant for the evaluation of the addressed sustainability criteria within BNB, but also separated into construction elements (cost groups according to EN 276) or relative to the life cycle stages (Fig. 6).

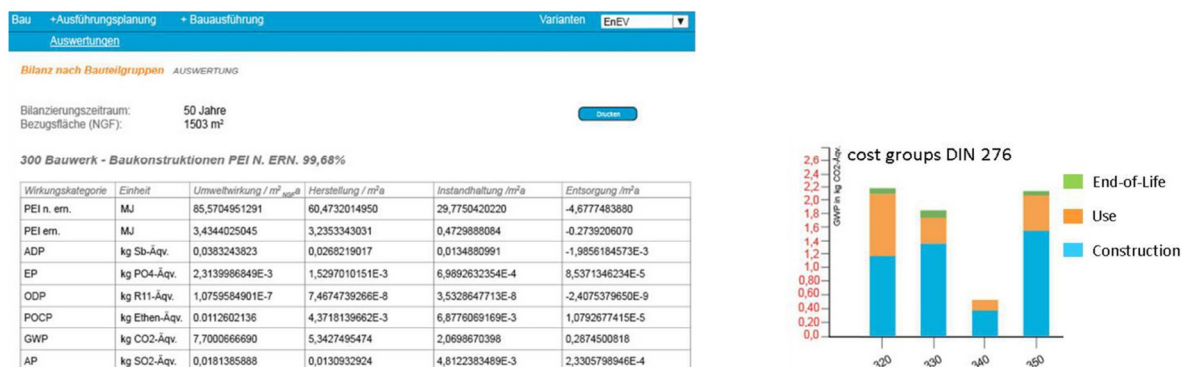


Figure 6: eLCA - Total score result and separation of results to cost groups and life cycle stages (left: table of results for environmental indicators; right: results of GWP in cost groups and life cycle stages)

First users all emphasized the userfriendliness of the tool and were highly satisfied with this tool. Ideas of an English version of eLCA are currently being discussed.

## Summary

The possibility to directly import of data into the online ÖKOBAU.DAT database with a given harmonised data format which follows the generally accepted European standards is a great chance for the idea of a consistent and comparable establishment of life cycle assessment within the context of sustainability considerations in the construction field. Some European countries are already highly interested in using the developed data format and finding a way of integration of their data to the ÖKOBAU.DAT. These developments of the new ÖKOBAU.DAT data format and organisation in an online data system are in the phase of first applications. There is a high potential for a harmonised and consistent way of using material and product relevant LCA data, or EPD data respectively, for life cycle assessment on building level.

## References

- [1] Brockmann, T. (2013) *Ecological Aspects of Building Materials/BNB*, SB 13 Helsinki.
- [2] BMUB (2014-05-20) Guideline for Sustainable Building.  
<http://www.nachhaltigesbauen.de/sustainable-building-english-speaking-information/guideline-for-sustainable-building.html>
- [3] DIN 276 Kosten im Bauwesen (*costs in civil engineering*).
- [4] EN 15804 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.
- [5] Kusche, O. et al. (2013) *Extending the ILCD Format to support Environmental Product Declarations of Construction Products*; EnvironInfo Hamburg.



## **Sustainable urban housing. Strategies for implementation in Bogotá**

### **Authors:**

**Gordillo, F<sup>1</sup>; Hernández, N<sup>2</sup>.**

### **Abstract**

*Urban housing component of the built environment, establishes guidelines for the consolidation of human settlements and the creation of infrastructures that support a comprehensive urban development. It includes activities of building industry, public housing programs, design and provision of social services.*

*While the policy of friendly, inclusive, and sustainable cities considered compact housing as urban factor, questions arise about what the sustainable resource are saving strategies and guidelines which enable its implementation in certain environments with sustainable technological principles.*

*To establish strategies for the development of living spaces from concepts of sustainable housing in their environmental, technological and social dimensions, with evaluation indicators to be applied in housing solutions of Bogotá, theoretical and practical references are obtained related with environmental, technological, social and legal aspects of urban housing policy in the context of Sustainable Construction.*

**Keywords:** *Housing, Sustainability, Environment, City, Building, Habitat.*

### **Background and diagnosis**

This work is generated from the study developed in the document "Guidelines for Sustainable Construction in Colombia" (2008) in which theoretical patterns from technology, management and the environment, should contribute to the generation of a determined Sustainable Construction in Colombia.

Although housing has been perceived as the most critical path to achieve sustainable construction, most interventions have not considered their socioeconomic and biophysical conditions. Also, to combine sustainability with policies or guidelines of housing, this constitutes one of the most important actions for sustainable construction in developing countries. Large infrastructure projects to provide are not motivated by a sustainability policy, but by the need to improve economic indicators in the generation of employment with construction activities and solve the guidelines generated by political purposes.

In Colombia there is a policy to attract friendly, inclusive, compact and sustainable cities (DPN, 2005), but to consider home as a housing solution and determinant of urban

---

<sup>1</sup> Consultor – Investigador Independiente, Bogotá, Colombia, gornando@gmail.com

<sup>2</sup> Consultor – Investigador Independiente, Bogotá, Colombia, nievesl.hernandezc@gmail.com





development, questions arise that challenge sustainable strategies for saving water and energy, possible guidelines adopted to consider the environmental conditions of the land -as topography and climate- that allow deployed in the housing, and how materialize the principles of technological sustainability, namely, recovery, renewal, and recycling of structures and building materials. So what is the riddle of sustainable strategies to implement housing policy to address the premise of building friendly, inclusive and sustainable cities are.

### **Principles of sustainability in construction and components of Habitat Build**

Construction is sustainable when applied the principles of sustainable development lifecycle of construction, from extraction and processing of raw materials to its deconstruction and waste management by planning, design and construction of buildings and infrastructure. It is a “holistic process” that seeks to harmonize and restore the natural milieu and the built environment, while forging settlements that ensure human dignity and economic balance. The understanding of sustainable construction goes beyond a biophysical impact on the built environment and its concept transcends environmental sustainability, to include economic and social sustainability and emphasize the added value of the quality of life of individuals and communities.

Housing is as Bollnow (1969), a place (experiential space), where sensations are fused, the individual needs and family or social relationships, which does the job to protect, to serve as shelter, covert. The construction of housing as the highest expression of built environment is a dynamic system, because as a system, is itself a service mechanism that responds to the satisfaction of existential needs of the individual. And as a function, it is an organism in which are combined the place, materials and financial resources to achieve product character, namely, use value and exchange.

The Urban Housing can be classified as formal and informal, in a context of massive housing solutions for people of higher or lower (better or worse) resources. In environmental and technological livability, sustainable urban housing construction falls under low initial costs, productive life cycles, good quality, recognized financial value, alternative production methods, and organized community efforts for the planning, management and conservation environment.

To develop a program of building homes with a focus on sustainability, an indicator development is needed for the evaluation of projects with sustainable criteria and, in this regard, here are six aspects with which housing impacts on the environment mentioned: the water consumption, energy supply, the fate of solid and liquid waste, the use of building materials and bio-climatic adaptability (Albalat, 2005).

Housing is more than shelter and stands as one of the components of a human settlement. Usually, it is seen as a product that is manufactured and delivery, rather than an elaborate process and associated. To make housing sustainable, programs that it promotes should integrate urban and ecological infrastructure with adequate social services.

Sustainability of built environment generates a manifest challenge to the demand for resources and experiences. The demand for "possible housing" should be more than a



production capacity and reserves, and become a neuralgic opportunity for the construction industry to achieve adequate levels of sustainability with regard to the impacts and opportunities in the formal sector, adapting models and processes based on knowledge of the informal communities that are characterized by their low cost and joint work.

The development of technologies, systems and innovative and competitive construction processes, ensures higher standards of quality and safety in the building, and improve the overall competitiveness of the construction sector through its modernization and automation. Industrialization streamlines the construction process to reduce execution times, workplace hazards, environmental impacts and economic resources.

New technological possibilities allow, and social needs so require, contemplate the fact constructive in its full cycle, from conception to its deconstruction, considering it as a process of integration of passive and active, permanent and temporary systems, provided by agents involved in each stage of the cycle, exceeding the targeting maintained until now in partial aspects of the construction process.

To create a sustainable built habitat, and in the property is implicit, we must begin to mimic natural processes that will identify new forms of heating, ventilation and waste management, by exploring all levels from manufacturing to materials, to planning and management of cities, with emphasis on the use of energy and renewable resources, recycling and imminent scientific revolution in biotechnology.

### **Dimensions of built environment**

The degree of development necessary to achieve a sustainable habitat, it must consider four areas: environmental sustainability, economic growth, social equity and technological development. Consistent with this, this study addresses the issue of the environmental aspect related with the place and understood as: geographical, natural and artificial; in the technological aspect is the action to the mechanization of the satisfaction of needs to live, especially construction technologies, that can be classified by systems (processes) and materials (technical); finally, the social field, is related to individual and collective interactions, economic development, indicators of quality of life, and forms of production.

In what has to do with the constructive aspects, from the environmental dimension, is necessary to seek the efficient use of resources, management of urban biodiversity, and planning and use more efficient of land with declining consumption of soil. From the social dimension, should allow for increased social participation and increased life expectancy. This is achieved if, in economic size, productivity growth is reached, the increase in income and wealth, and improving infrastructure. In the technological dimension, interactions that the individual and society and made with the environment are manifested, they get to this economic developments and possible habitats built for shelter and enjoyment of various social groups as a solution of basic needs, spiritual, individual and collective . All this is possible if there is an improvement in the regulation and governance from the political dimension.

Environmental Dimension. The environment is the set of physical, biological and chemical variables of a geographical space where activities are carried out with physiological and



psychological sensations. The city is an ecosystem surrounded by others that are subsystems of the biosphere; besides generate waste and transformed quantities of matter, energy and information. The atmosphere has three main functions in the economic activity of man: supply resources -water, energy and materials-; assimilation of the waste generated by the use, transformation and consumption of resources and generation of other environmental services, such as physical and biological autoregulation of the environment, or the satisfaction of other, cognitive, aesthetic, spiritual and recreational needs.

Sociocultural Dimension. Cities are the most efficient human organization to create, transmit, accumulate and evolve cultural information. The main social actors generate flows of information related to the representation that each actor makes the environment, their relationship with its, and the relationship to others and to himself. The economic system aims to meet human needs and wealth generation, combining the public good and the particular. Consumption habits are formed from these requirements and their interaction with physical and social factors of accessibility, income levels and cultural model of each population group within the city.

Technological Dimension. So-called "technology standards" do not prevail for use in any scenario and appropriation of foreign technologies , which usually are commercially imposed by producing new sources of fictional resources , cause usually conflicts between the territory and society supposed to serve. Here, Santos (2000) argued with some justification, that technology can become a destructuring component socio-economic, political, cultural, spatial, etc., effects which result in a reorganization of territories.

### **Indicators for sustainability and proposed strategies**

Generating indicators that empower the valuation of buildings with sustainable criteria and suitable for development and contribution to the rationalization of the construction and management processes for satisfactory enjoyment, enabling consensus decision making, is essential. At present, the demand for social sustainability becomes a requirement to techniques and products that focus on improving quality standards and for this, there are different methods for assessing the sustainability of buildings, called indicators, which allow trends to be the evolution of their specific parameters.

Then the proposed strategies for design, construction and operation of sustainable housing are presented. It aims to encourage and enable the acceptance and implementation of sustainable practices in urban housing from the creation and implementation parameters and verifiable criteria.

The four dimensions described, transversely relate to each other, and they focused activities to fulfill specific needs in the field of urban housing. Chosen were key factors inherent in sustainability, accessibility and quality of life in urban housing in Bogotá, namely sustainability of the place, efficient management of financial resources, conservation of water resources, energy efficiency, use of appropriate technologies to the environment, selection of materials and resources, environmental quality in interiors and well-being of the user.

The evaluation parameters, focus on sustainable site development and respect for the environment, climatic conditions, the efficient management of economic and financial



resources, the proper use of water resources, efficiency in the use of clean energy sources, innovation in construction and significant advance over conventional methods, integration of innovation in materials and construction products, taking care of non-renewable materials and respect for raw materials and protected areas, innovative concepts in design, structure, enclosure and construction services, and patterns of behavior that govern sustainable community.

## 1. Environmental and Technological Dimension

### a. Area: Sustainability place.

Parameter: Sustainable development of the site and respect for the environment.

Indicators:

- Site selection and ecological value. Building footprint and impact on the environment.
- Construction of suitable housing. Inappropriate land use.
- High level of architectural quality and aesthetic impact on their cultural and physical context.
- Mobility, accessibility and relationship with the urban context. Public transport.
- Recovery of central areas of the city. Reuse of buildings.
- Maintenance of the urban ecosystem, landscaping and project equipment. Vegetation used and ratio of soft and hard areas.

### b. Area: Conservation of water resources and energy efficiency.

Parameter: Use of water resources and efficiency in use of clean energy sources.

Indicators:

- Management of water resources. Efficient water treatment discharges and wastewater reuse.
- Management and Energy Efficiency. Use of Renewable Energy.
- Use of natural light and energy consumption in building operation.

### c. Area: Use of appropriate technologies to the medium.

Parameter: Innovation in construction and significant advance over conventional methods.

Indicators:

- Innovations in technology construction processes, operation and maintenance. Energy used in the process of construction of the building.
- Effectiveness of the construction process. Compliance with current regulations.
- Prevention of emergency evacuation. Emission standards and climate change.

### d. Area: Selection of materials and resources.

Parameter: Innovation in integration of materials and construction products.

Indicators:

- Management of construction waste. Recycling: storage and collection
- Responsible use of natural resources, including operation and maintenance.
- Energy used in the production of construction materials
- Use of local and regional materials. Origin and certification of the woods. Materials Eco label.
- Materials selected for their environmental impacts and human health.

### e. Area: Environmental quality in interior spaces.



Parameter: Innovative concepts in design, integration of materials, structure, and construction services.

Indicators:

- Control systems and comfort: acoustic, visual, hydrothermal, olfactory, health.
- Flexibility against future changes of users, ownership and regulations.
- Thermal mass of the building. Ventilation and temperature occupied housing.
- Acoustic design of housing. Luminance Control. Indoor air quality.

#### Environmental and Economic Dimension

a. Area: Management means.

Parameter: Efficiency of economic and financial resources.

Indicators:

- Economic performance and compatibility. Operational control and maintenance.
- Total cost of lifecycle housing. Spatiality of housing as needed.
- Adherence to ethical standards in all project phases. Eco-efficiency and environmental quality.
- Costs in service networks, infrastructure and transport. Resource Economics.

#### Environmental and Sociocultural Dimension

a. Area: Social Aspects.

Parameter: environmentally sustainable behavior patterns that govern the community.

Indicators:

- Involvement of stakeholders. Housing spatiality from the social inclusiveness.
- Level of maintenance of the building.
- Design spaces and enclosures, selection of materials, bioclimatic architecture.
- Sustainable behaviors (recycling, low energy consumption and resources).
- Prevention and adaptation to climate change. Ethical standards and social equity.

The relationship between housing and the environment, affecting both the ecosystem and the “urbsystem”, and require the adoption of updated assessment guidelines that take into account the life cycle of buildings, as well as systems, elements and components of the construction activity for a harmonious development of the city and support the achievement of healthy environments and housing spaces .

### **Conclusions**

From the environmental and technical dimensions, are tending towards more efficient use of energy resources and the integration of urban biodiversity.

From the social dimension, seek the increased quality of life; this is accomplished if the economic dimension of productivity growth and improving infrastructure is reached.

All this is possible if there is greater participation in decisions and an improvement in the application of the rule from the political dimension.



<b>Table 1. Indicators for sustainable urban housing</b>	
<b>Sustainability of the site</b>	<i>Sustainable development instead of a place and respect for the environment</i>
<b>Effective management of financial resources</b>	<i>Effective management of financial resources</i>
<b>Water conservation and energy efficiency</b>	<i>Proper use of water resources and efficient use of clean energy sources</i>
<b>Using appropriate technologies to the medium</b>	<i>Innovation in sustainable construction and significant advance over conventional methods</i>
<b>Selection of materials and resources</b>	<i>Innovative integration of materials and construction products</i>
<b>Environmental quality in interior spaces</b>	<i>Innovative design, integration of materials and products, structure, premises and construction services concepts</i>
<b>Social aspects</b>	<i>Environmentally sustainable behavior patterns that govern the community</i>

## References

- Albalat, H. (2005). *"Sustainable Housing. Facilities alternate"*. Conference 1st International Conference on Sustainable Development Successful Cases Tropics. Veracruz 2 to May 4, 2005. Digital document.
- Alcaldía Mayor de Bogotá (2002). *Environmental Management Plan 2001-2009*. Bogotá: Administrative Department of the Environment. Digital Document.
- Alcaldía Mayor de Bogotá (2008). *Environmental Management Plan 2008-2038*. Bogotá: Department of Environment. Digital Document.
- Aulí M. (2005). *Guide to sustainable housing*. Barcelona: Ceac.
- Bollnow, O. (1969). *Man and Space*. Barcelona: Editorial Labor, S.A.
- DPN (2005). *Vision 2019 Bogotá Colombia*. Department of National Planning. Digital document.
- DNP (2004). *Guide for developing indicators*. Bogotá: National Planning Department. Digital document.
- Du Plessis, Chrisna (2002). *Agenda 21 for sustainable construction in developing countries*. Pretoria: CSIR Building and Construction Technology.
- Gordillo, F.; Hernández, N.; Ortega J. (2008). *Guidelines for sustainable construction in Colombia. Bogotá, Cali, Medellin*. Bogotá: Universidad Colegio Mayor de Cundinamarca – Consejo Profesional de Arquitectura.
- Heidegger, M. (1951). *"Building, dwelling, thinking"*. Conference. Digital document.
- Martínez, C. (2007). UN Habitat Mexico. Conference *"Where housing goes."* Forum. Bogotá: National Savings Fund and Casa Editorial El Tiempo. September 2007
- Mertins, G. (2008). *Megacities in Latin America*. Bogotá: Conference "International Forum 2038 Bogotá."
- Santos, M. (2000). *The nature of space*. Barcelona: Editorial Ariel.
- UN Habitat Program (1976). *United Nations Conference on Human Settlements*. Istanbul: in: <http://habitat.aq.upm.es/aghab/aproghab.html>.
- UNCED: UN Conference on Environment and Development (1992). *"Rio Declaration on Environment and Development."* Agenda 21. Digital document.

## **A Multi-scale Method to Optimize the Sustainability in Construction Works**

Gargiulo, Carmen<sup>1</sup>; Daniotti, Bruno<sup>2</sup>

<sup>1</sup> ABC Department, Politecnico di Milano, Milano, Italia

<sup>2</sup> ABC Department, Politecnico di Milano, Milano, Italia

**Abstract:** *Thanks to the contribute of the international scientific community, the life-cycle approach has become essential in the assessment methodologies of sustainability in construction works.*

*However, this approach generally treats the building as an isolated object, omitting its relationship with the surrounding urban and territorial context. Additional research assumes the building as a part of a wider context.*

*On the other hand, since the problem to contain the natural resources use has been raised, many international organizations and authorities have issued acts and programs to reduce energy use and carbon emissions.*

*The paper presents the results of the original research focusing the multi-scalarity as a driver to evaluate performances, impacts and benefits of a set of operations on a building.*

*The proposed multi-scale, performance oriented and life-cycle method aims optimizing the sustainability of the building, in relationship with its territorial context, from the neighborhood to the urban and larger spatial scales.*

***Multi-scale, rating, sustainability assessment, carbon emissions, energy saving, benchmarking***

### **Introduction**

The life-cycle approach has become essential in the assessment methodologies of sustainability in construction works [1].

However, this approach generally treats the building as an isolated object, omitting its relationship with the surrounding urban and territorial context. Additional research expands environmental assessment to the city level, assuming the building as a part of a wider context and the consequences of any operation on the building not limited at its own boundary, but affecting the upper scale areas, from the neighborhood to the higher spatial scales.

An analysis of the state of the art shows that for the assessment of sustainability of construction works in a life cycle approach the most commonly used rating systems / multi-criteria tools are generally inconsistent one with each other. Actually, this limitation represents also a barrier to the progress of sustainability in the building sector.

At the European level, there is an ongoing process by the European Technical Committee for Standardization CEN TC 350, in order to develop common rules for the assessment of the environmental, social and economic performances of new and existing buildings within the

framework of integrated performance of buildings. This is a response to Standardisation Mandate M/350 addressed in 2004 to CEN by the EC/DG Enterprise for the so called development of horizontal standardized methods [2] for the assessment [3] of the integrated environmental Performance of buildings.

At the same time, at the international level [4] a discussion on wider system boundaries, beyond the building, is going on. On the other hand, since the problem to contain the use of natural resources and the anthropic actions has been raised, a certain number of international organizations and authorities (from governmental to local) have issued acts, programs, action plans, directives to press the economic sectors, including building, to reduce mainly energy use and carbon emissions.

The research focuses the *multi-scalarity* as a driver to *evaluate* performances, impacts and benefits of a set of retrofitting operations on a building that is a part of a real estate asset. The case study consists in a rationalist building located in the main of the city Campuses of Politecnico di Milano (Fig. 1, 2). The “Leonardo Campus” occupies a surface of 186,613 m<sup>2</sup>, with a population of 17,484 students and, in addition, 1,748 staff. The Building n.14, so called “La Nave” for its particular shape looking like a ship, was built in 1965 and the designer, Giò Ponti, is considered one of the major Italian modern. This is the reason why the retrofit applications and maintenance operations on this building face aesthetic constraints, making particularly interesting the challenge of both optimization and sustainability.

Actually, previous studies had identified a set of design alternatives, in application of an operational strategy paying particular attention to energy saving, carbon emissions reducing and indoor comfort improving. The selected 43 alternatives cover the following categories: roof insulation, windows replacements, HVAC and lighting control and automation. Included is also a partial façade renovation, with replacement of single antiquated and energy-intensive components, like glass blocks.



## Methodology

The results are achieved throughout the development of a multi-scale, performance oriented and life-cycle method. The scope of the method is actually optimizing the sustainability of the building in relationship with its territorial context, from the neighborhood to the urban and higher spatial scales.

The first stage of the research has included a first wide analysis and preparatory studies, aiming to identify Indicators and Benchmarks. A wide study has taken in account the European indicators/aspects and methodology identified by the CEN TC 350 Standards [4], and the drivers of the current developments. A first panel of indicators has so been set, grouped in environmental, social and economic indicators. Thanks to a further recognition in literature, reporting the results of researches validating additional indicators, an additional list of indicators has been selected. A conceptual model reporting the levels of the building, the campus, the city, the metropolitan area and the national-European framework has been drawn to support the territorial contextualization of the European indicators (Fig. 3).

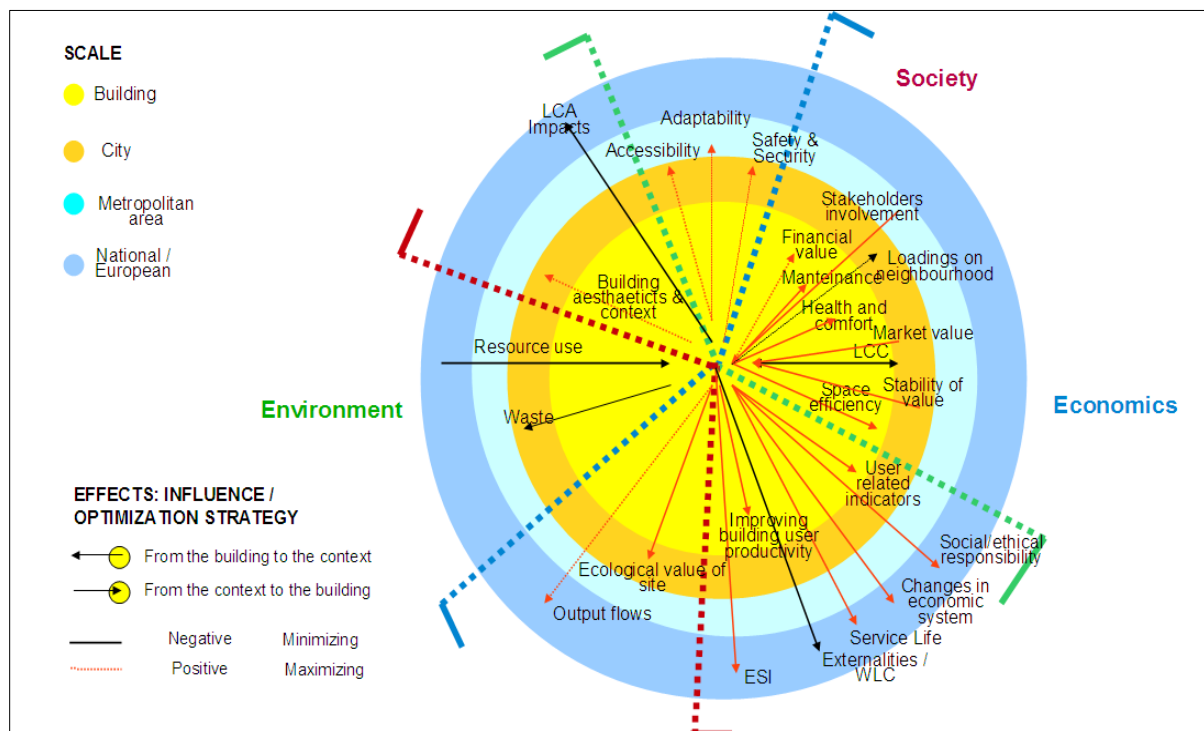


Fig. 3: Contextualization of the European indicators

On the other hand, the results of a research on the assessment and reporting studies applied to the case study have allowed to identify a large number of evaluations of the sustainability at the different scales of the territory in which the Campus [5] is located, from the city level to

the national / European level, going through the metropolitan and regional scales and also including some international university ranking systems. The information has been organized with the aid of the ISCN (International Sustainable Campus Network) grid. The highlighting of the *inter-relations* between aspects and indicators, describing the performances of any single building with the campus and of the campus with the city, has immediately confirmed the hypothesis that it is possible to approach the assessment of sustainability looking at the performances of a building, before and after a retrofit operation, from a multi-scale and transversal point of view.

The last preparatory deepening has started from the list of indicators/aspects identified in the previous stages further restricting the list of indicators/aspects suitable to the case study, as the result of splitting up the total list in two different lists, even if overlapping for such elements. This operation is derived from the assumption that the construction works on an existing building can be divided in two main categories: renovation on technological systems and operations changing the layout even if of a part of it. The difference falls on the choice of indicators. In the study case, for example, this implies that the set of indicators for the assessment of the alternatives exclude indicators referring to spatial efficiency or accessibility.

A parallel study has been conducted on the campus, comparing the performances of the Leonardo Campus particularly in terms of energy consumption, carbon emissions and accessibility, to the corresponding performances per unit, at the city level and in the framework of some reference worldwide campus. Moreover, comparing the performances, per unit, of the building “La Nave” to the Campus. This study has produced results useful to measure the incidence of such operations on the building on the whole campus.

An additional deep research has looked for strategic plans and programs, from the local to the global scale, putting direct or indirect targets to indicators closely related to the building. The analysis of literature has included more than 40 reports and strategic documents, going from the current action plan for the educational building of the Milano Council, to the most recent regional environmental programs, to the governmental measures in the fields of energy, to the OECD and EU environmental measures. Extrapolating the ones matching with the case study, that is a both civil, tertiary and educational building, has been set out, in form of *percentage of reduction for energy consumption and carbon emissions cut-off* has been set out (Tab. 1).

The panel of the “territorial” targets has subsequently contributed to set out a panel of *key Indicators*, among those identified in the lists European CEN TC 350 standards and grouped in base of the scale and the area of sustainability, as below listed:

#### 1. Indicators *at building level*

##### 1.1 Environmental sustainability:

- Total embodied energy (EE) [MJ / m<sup>2</sup>]

##### 1.2 Social sustainability:

- Thermal comfort characteristics (Ct h / Ct c) [PMV – °H]



- Acoustic characteristics [dB]
- Indoor air quality (IAQ) [PPD %]
- Visual comfort (I) [PsupD %]

### 1.3 Economic sustainability:

- Life cycle costs: initial investment (CI), operational (CO), end use (CD) [Euro]

## 2. Multi-scale indicators:

### 2.1 Environmental sustainability:

- Primary energy (EP) [kWh / m<sup>2</sup>]
- Global warming potential GWP (CO<sub>2</sub> eq) [kg CO<sub>2</sub> / m<sup>2</sup>]

Tab. 1: Targets for Global Warming Potential adopted in the benchmarking

Carbon emissions: category	ECONOMIC SECTOR			
	All	No ETS	Civil	Tertiary
Direct+Indirect	-20% MI 2020 (1)	-6% Lombardia 2020 (2)	-0,04% Metr. Area MI 2010 (3)	-0,6% Lombardia Region 2020 (4)
	-21% MI 2020 (5)		-24 kg/ m <sup>2</sup> y EU27 2020 (6)	
	-20% to -30% EU27 2050 (7)		-13,5% EU OECD 2050 (8)	
	-40% to -44% EU27 2030 (9)		-35% EU OECD 2050 (10)	
	-75% EU OECD 2050 (11)		-37% to - 53% EU27 2030 (12)	
	-79% to - 82% EU27 2050 (13)		-88% to - 91% EU27 2050 (14)	
Direct	-20% MI 2020 (15)			-1,4% MI 2020 (16)

(1): Piano d'azione del Comune di Milano per l'energia sostenibile e il clima Elaborazioni IEFÉ-Avanzi su dati AMAT (2009); (2) PLS Piano Lombardia Sostenibile 2010; (3) Programma di efficienza energetica della Provincia di Milano – 2006; (4) PLS Piano Lombardia Sostenibile 2010; (5) Decreto Interministeriale Ministero Sviluppo Economico e Ministero Ambiente 8 marzo 2013 (Strategia Energetica Nazionale); (6) SuperPerBuildings Final Report, 2012: Economic assessment of the refurbishment of eternal walls (Petersdorff et al. 2005), “Towards low Energy buildings, Energy saving and CO2 emission reduction by changing European building regulations to very low energy standards”; (7) EU Climate-Energy Package 2009; Commission Staff Working Document accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions “Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage”; (8) IEA – ETP 2010 su scenario BLUE Map Europa-OECD; (9) COM(2011) 112 final “A Roadmap for moving to a competitive low carbon economy in 2050”. Communication from the European Commission, Brussels, 8.3.2011; (10) IEA – ETP 2010 su scenario BLUE Map Europa-OECD; (11) IEA – ETP 2010 su scenario BLUE Map Europa-OECD; (12) COM(2011) 112 final “A Roadmap for moving to a competitive low carbon economy in 2050”. Communication from the European Commission, Brussels, 8.3.2011; (13) COM(2011) 112 final “A Roadmap for moving to a competitive low carbon economy in 2050”. Communication from the European Commission, Brussels, 8.3.2011; (14) COM(2011) 112 final “A Roadmap for

moving to a competitive low carbon economy in 2050". Communication from the European Commission, Brussels, 8.3.2011; (15) (16) Piano d'azione del Comune di Milano per l'energia sostenibile e il clima Elaborazioni IEFE-Avanzi su dati AMAT (2009).

Downstream the steps above described and an additional study comparing the 43 options [6] in base of each one of the key indicators (environmental, social, economic) with respect to the State of Art (SDF), a double *rating system* has been built, with the support of the following elements: Scenarios: 2020 / 2050; Macro-criteria: Environmental / Social / Economic sustainability; Criteria: nu.12; Classes: A, B, C, D (2020); A, B (2050); Profiles: Pa,b; Pb,c; Pc,d (2020); Pa,b (2050).

## Results and conclusions

The results of the rating procedure, aided by a sensitivity analysis, reward mostly the technical solutions that not only meet more the 2020 and 2050 environmental requirements (carbon emissions and primary energy), but also show balanced performances in the other areas, with emphasis on some of the economic ones.

Moreover, the method [7] shows to be able to aid the owner and the project managers in a virtuous process of continuous improvement of the asset [8] in a wide sustainable perspective, confirming the initial hypothesis that it is possible and highly recommended, to adopt a *multi-scale* and *multidisciplinary approach* [9].

From a specific point of view, the proposed performance management method, based on a life cycle approach and adopting a benchmarking [10] related to the context, shows to be able to support the decision-making, rating the technical alternatives in base of their *multi-scale sustainability*, assigning from A (high) to D (low) classes of sustainability, in two different scenarios: short-medium and medium-long term.

Further developments may be leaded in the direction of the introduction, in the rating procedure, of additional criteria, referred to the use of natural resources, waste production and recycling. Also, the method may be implemented on a wider range of construction works, such as residential buildings, civil engineering works and larger assets, like groups of buildings, even building stocks and urban [11] districts. The flexibility of the method suggests also a further development with respect to case studies located in different geographical areas, replacing or enclosing new indicators.

## Acknowledgements

The research has been developed under the supervision of Prof. Bruno Daniotti and Prof. Gabriele Masera of Politecnico di Milano (Department ABC) and the co-supervision of Prof. Alberto Colorni of Politecnico di Milano (Poliedra) for the MCDM analysis. Dutiful gratitude is directed to Prof. Thomas Lützkendorf, head of Chair for Sustainable Management of Housing and Real Estate at the School of Economic and Business Engineering of the Karlsruher Institut für Technologie (K.I.T.), for his collaboration as an external co-supervisor to define the strategic guidelines of the proposed methodology and to Prof. Christian Stoy and his research staff of Institut für Bauökonomie at Universität Stuttgart for their hospitality targeted to the insights on the economic indicators and methodologies. Finally, I extend my



sincere thanks to the co-examiners Prof. Monica Lavagna and Prof. Eugenio Morello of Politecnico di Milano.

## References

- [1] Daniotti, B. (2012) *Durabilità e manutenzione edilizia*, Torino, Editore UTET scienze e tecniche. ISBN:978-88-598-0847-3.
- [2] Daniotti, B., Re Cecconi, F. (2010) *Test methods for service life prediction*. CIB.
- [3] Lavagna, M. (2008) *Life cycle assessment in edilizia. Progettare e costruire in una prospettiva di sostenibilità ambientale*. Milano, Italy, Hoepli. ISBN:978-88-203-4075-9.
- [4] Ilomäki, A., Lützkendorf, T., Trinius, W. (2008). Sustainability Assessment of Buildings in CEN/TC350 Sustainability of Construction Works, *Proceedings of the World Conference SB08*. Melbourne, Australia. ISBN:978-0-646-50372-1.
- [5] Bruglieri, M., Ciccarelli, D., Colorni, A., Luè, A. (2011). PoliUniPool: a carpooling system for universities, *14th Meeting of the Euro Working Group on Transportation*. Poznan, Poland.
- [6] Maltese, S., Daniotti, B., Re Cecconi, F. (2013). Sustainability Multi-Criteria Analysis Method – Real Estate Assessment Tool for a Sustainable Refurbishment, CESB13 Prague. “Central Europe towards Sustainable Building 2013”: *Sustainable Building and Refurbishment for Next Generations*. Prague, Czech Republic: 705-708. ISBN:978-80-247-5015-6.
- [7] Gargiulo, C. (2012). Performance oriented building assessment: time and space the two dimensions of sustainability, *CIB W115 Green Design Conference Proceedings* ISBN:978-90-365-3451-2, Sarajevo, Bosnia and Herzegovina, 27-30.
- [8] Gargiulo, C. (2013). A multilevel and multiscale method to optimize the sustainable construction works. *SB13 Munich. Implementing Sustainability – Barriers and Chances*. Munich, Germany: 1032-1039. ISBN:978-3-8167-8982-6.
- [9] Gargiulo, C. (2013). A Multilevel Method to Manage the Complexity of the Sustainable Construction Works. *SB13 Oulu. Sustainable procurement in urban regeneration and renovation Northern Europe and North-West Russia*. Oulu, Finland: 205-213. ISBN (E-Book): 978-951-758-562-0.
- [10] Gargiulo, C. (2013). Performance Oriented Building Assessment: a Decision-support Method based on an Integrated Approach. *CESB13 Prague. Central Europe towards Sustainable Building 2013: Sustainable Building and Refurbishment for Next Generations*. Prague, Czech Republic: 1-10, ISBN:978-80-247-5018-7.
- [11] Morello, E. (2011) *Urban morphology and environmental quality: tools for evaluation and design*. Kien Truc: 98 – 103. ISSN: 0866-8617, 193.

## Service life of UK supermarkets: origins of assumptions and their impact on embodied carbon estimates

### Authors:

Richardson, S.<sup>1</sup>; Hyde, K.<sup>2</sup>; Connaughton, J.<sup>2</sup>; Merefield, D.<sup>3</sup>

<sup>1</sup> TSBE Centre, University of Reading, Reading, United Kingdom

<sup>2</sup> SCME, University of Reading, Reading, United Kingdom

<sup>3</sup> Sainsbury's Supermarkets Ltd., London, United Kingdom

**Abstract:** *Life cycle Assessment (LCA) methods have been gaining interest within the construction industry for assessing environmental sustainability, particularly carbon emissions. Understanding the relative significance of different lifecycle phases is important when making design decisions to reduce carbon emissions. For certain building types, such as offices, embodied carbon represents a significant proportion of whole-life carbon emissions, with some studies suggesting estimates of 50% or more of total emissions. This is not thought to be the case for Supermarkets where operational emissions are claimed to be predominant due to high annual consumption of energy.*

*Crucial to the apparent significance of embodied carbon, relative to the whole lifecycle, are the assumptions made about building service life. Yet despite their importance to assessment outcomes, a review of the literature shows that many studies provide little justification for these assumptions. Assertions about the relative weighting of different lifecycle phases within the overall carbon footprint are therefore questionable.*

*A new approach to the selection of service life is proposed that uses historic data on the service lives of similar buildings. This helps to identify an appropriate range of service lives for a parametric analysis of embodied carbon.*

*In a study of UK supermarkets, we find that service life can vary from 15 years to over 50 years. Applying the new approach for this range of service lives we show that the proportion of lifecycle carbon due to embodied emissions can more than double, compared to more conventional approaches. For one of the case-study buildings the embodied carbon would be over 55% of the lifecycle carbon emissions for the minimum service life case of 15 years.*

*We conclude that when estimating the whole-life carbon emissions of a building, assumptions about service life are critical, requiring evidence-based justification. The approach presented offers a new way to address this problem. This will lead to improved understanding of the importance of different lifecycle stages and facilitate better informed design decisions in regard to carbon reduction measures. Further work to understand the factors, such as obsolescence and competitor activity that affect the service life of supermarkets in practice is recommended.*

**Keywords:** *LCA; Embodied Carbon; Design Service Life; Supermarket Construction*

### Introduction

Reducing carbon emissions in the built environment has been identified as a key target in climate change mitigation efforts at both UK [1] and EU level [2]. Historically, much attention has been paid to energy and carbon emissions from the operation of buildings. More recently there is increasing concern about embodied energy and carbon, which is that 'associated with extraction, manufacturing, transporting, installing, maintaining and disposing

of construction materials and products' [3, p. 28]. Some UK studies suggest that embodied carbon can represent more than 50% of the whole life carbon emissions of certain types of buildings, such as offices or warehouses, whilst acknowledging that more energy-intensive building types, such as supermarkets, will have a lower ratio of embodied carbon to operational carbon (henceforth EC:OC) [4], [5].

Understanding the relative contribution of different lifecycle phases to total carbon emissions is important when making carbon reduction design decisions. Life cycle assessment (LCA) and related techniques such as life cycle energy assessments and carbon footprinting, present 'a scientifically established method for generation of the necessary decision support' [6, p. 920]. Such techniques have been applied to the study of buildings as far back as the 1970s [7], [8]. However, assumptions made in the application of these methods can have a significant impact on the results and should therefore be clearly stated [9] and ideally justified. Of particular importance in determining EC:OC is the assumption made about service life length. In general, the longer the assumed service life the more significant the operational phase will appear. [10], [11]. This is clear from the formula for life cycle energy (LCE) given in Equation 1 below, adapted from Ramesh et al [12].

$$LCE = \langle \sum m_i M_i + E_c \rangle + \langle \sum m_i M_i [(L_b / L_{mi}) - 1] \rangle + \langle E_{OA} L_b \rangle + \langle E_D \rangle \quad (1)$$

The terms demarcated within chevrons (from left to right) represent embodied energy of initial construction, embodied energy of subsequent refurbishment, operational energy and embodied energy of demolition respectively. In these terms,  $m_i$  is the quantity of material  $i$ ,  $M_i$  is the energy content of material  $i$  per unit;  $E_c$  is the construction energy requirement,  $L_b$  is the assumed service life of the building in years;  $L_{mi}$  is the assumed service life of components in years;  $E_{OA}$  is the annual operating energy demand;  $E_D$  is the energy requirements for demolition.

Building service life  $L_b$  (in years) is a multiplier in both the recurring embodied energy term and the operational energy term, and will have a noticeable impact on the results. A similar approach would apply to assessing lifecycle carbon emissions or indeed any other LCA impact category. Moreover the greater the contribution of operational impacts to the whole lifecycle, the greater will be the effect of varying the service life on the proportional contribution of initial embodied impacts. This is particularly germane for supermarket buildings where operational impacts are high relative to other building types [4], [5].

### Terminology

In this paper the term service life is defined according to BS EN 15643 *Sustainability of construction works — Sustainability assessment of buildings* as 'the period of time after installation during which a building meets or exceeds the technical requirements and functional requirements [13]. It is assumed that the end of the period within which those requirements are satisfied will be marked by demolition or significant change of use of the building. The term *estimated service life*, according to BS EN 15643, involves consideration of the performance of a building and its components in specified conditions as compared to its durability under standard conditions [13]. In practice it was found that this approach is not currently widely applied at a building level and so when referring to the anticipated length of the building life applied to assess environmental impacts, the term *assumed rather than*



*estimated service life* has been used. Finally, in all the literature reviewed, the reference study period over which environmental impacts of the building were assessed was the same as the building service life and so the same approach has been adopted in this research.

### **Methodology**

Our review of the literature on LCA-based studies of buildings - including life cycle energy assessments and carbon footprint studies - illustrates a general lack of justification for service life assumptions, and suggests a need for a new approach. This review helps develop proposals for a potentially more robust approach by combining two of the more common methods found in practice. We then use this new approach on a case study of supermarket buildings in the UK. Data for this is taken from unpublished commercial carbon footprint reports prepared for Sainsbury's, a UK supermarket chain. This carbon footprint data is reassessed using revised service life assumptions developed from the new approach.

### **Service life assumptions in LCA and related studies**

Amongst the many LCA based studies of buildings published in the literature, which include lifecycle energy assessments and lifecycle carbon footprints, there is significant variation in the assumptions made about building service life. Reviews of such studies, have found assumptions range from 30 to 100 years for whole buildings [12], [14] and 10 to 100 years for buildings products [15]. Despite this wide variance, these reviews do not question or critique the service life assumptions or indeed make any reference to their justification.

In a study of US residential buildings, Aktas and Bilec find that 'many building LCA studies do not adequately address the actual lifetime of residential buildings and building products, but rather assume a typical value'[16, p. 338]. Among LCA-based studies of commercial buildings, unjustified assumptions about service life have also been observed [17]–[20].

In the specific case of supermarket buildings, only one study was found that assessed the whole lifecycle using an assumed service life of 20 years, stating that such buildings typically have a short life expectancy [21]. Five unpublished commercial studies covering six supermarket buildings undertaken privately for Sainsbury's Supermarkets from 2008-2012 were made available to the authors for analysis. Of these, four assumed a service life of 30 years whilst one, which covered two different buildings, assumed a 60 year service life for both. In all the studies, the assumed service life was stated without justification.

### **Options for defining service life assumptions**

Approaches to defining service life for LCA studies found in the extant literature can be divided into three categories. One approach is to use design life assumptions as a proxy for service life. A second is to use data on the actual past service life of similar buildings. The level of methodological complexity with which such data is used to develop trends varies significantly from those which give no detail on how trends have been analysed to those which apply probability distributions using monte-carlo analysis [16] or the life table method [22]. And a third is to use a range of possible service lives [23], [24]. This final option can be

considered a parametric approach because a range of results are generated for a range of input parameters, in this case, building service life.

The parametric approach provides a way to address the inherent uncertainty of assessing lifecycle impacts at design stage and is therefore preferred over the other two options. However, the choice of parametric input range for the service life remains to be justified and this could be done by applying one of the first two options.

In practice, claims about design life are often based on local structural building codes. For example, the Eurocodes quote 50 years as the indicative design life of ‘building structures’ [25, p. 28]. In many cases, this nominal design life bears no real connection to the actual durability of buildings [16], [26]. Furthermore, it takes no account of non-technical issues such as changing land values and occupant needs which often have a greater influence on actual service life than durability [26]. Design life is not, therefore a useful basis for assumptions about service life. Hence, the second option, which relies on observations about the actual service life of buildings similar to the one being assessed, may be preferable for defining the service life range to be applied in a parametric analysis.

This combined approach has been tested for the specific case of assessing the ratio EC:OC of UK supermarket buildings. The results of two studies undertaken for Sainsbury’s Supermarkets, originally based on unjustified single service life lengths, have been reassessed using a range of service life lengths determined from data on the service life of actual supermarkets. The purpose being, on the one hand, to demonstrate that the use of such historical trends to define a parametric service life range for the assessment may lead to different conclusions than the original assumptions. On the other hand the challenges and possible barriers to successfully applying this technique are also highlighted.

### Historical trends in supermarket service life

Data on the ages of almost 600 existing (still trading) supermarkets was gathered as well as additional data on supermarket closures. A range of sources was used including the supermarkets themselves and local records such as newspaper reports. Fifteen closures were identified, dating back to 2007. Of these, eight are known to have been demolished whilst the remaining seven are excluded because their current status could not be verified. The ages of the existing stores are presented in Table 1 and those of the 8 demolished stores are shown in Table 2 below.

*Table 1: Age distribution of a selection of existing (operational) UK Supermarkets*

Age Range	0-15 Years	15-25 Years	25-35 Years	35-45 Years	45-55 Years
Percentage of existing stores	40%	32%	19%	7%	2%

*Table 2: Ages of eight UK supermarkets demolished in the last eight years*

Store number	1	2	3	4	5	6	7	8	Mean Age
Age at demolition (years)	35	22	15	16	23	26	29	18	23

The data for the store closures shows that the service life of these stores varied from 15 to 35 years with the mean age being 23 years. This suggests that the assumptions of 30 and 60 year service lives applied in the studies of new supermarket buildings need to be reviewed.

According to this data, a parametric study using the range of 15 to 35 years would be more appropriate. However, Table 1 shows that just under 10% of the existing stores included in this study exceed this age range; the oldest store still operating being 52 years old. The mean age of existing stores is 18 years, and if those less than 15 years old (the earliest date of demolition recorded) are excluded, the mean value rises to 26 years. The two datasets may be combined to define an appropriate range for the assumed service life in a parametric study. For example, the range could be based on a minimum of 15 years, and a maximum 52 years, the highest age of the stores still in operation. Intermediate values can be selected whereby 25 years represents the rounded mean age of all stores older than 15 years, and 35 years is the age of the oldest store to have been demolished.

### Parametric techniques for estimating embodied carbon contribution

The ratio EC:OC for two of the studies provided by Sainsbury's was recalculated using a parametric approach combined with the data on store ages. These two stores were chosen because they have the lowest and highest proportional embodied carbon for their original assumed service life of 60 and 30 years respectively. They represent a standard specification store (Store 1) built to meet UK building regulations in 2010 without any significant energy efficiency improvements, and a highly energy efficient store (Store 2) which had a range of measures applied to reduce operational energy and carbon emissions and achieved BREEAM 'Very Good'. The percentage contribution of embodied carbon (initial and recurring) to the whole lifecycle are plotted in

Figure 1 for the range of service life lengths determined from historical data and including the originally assumed service life.

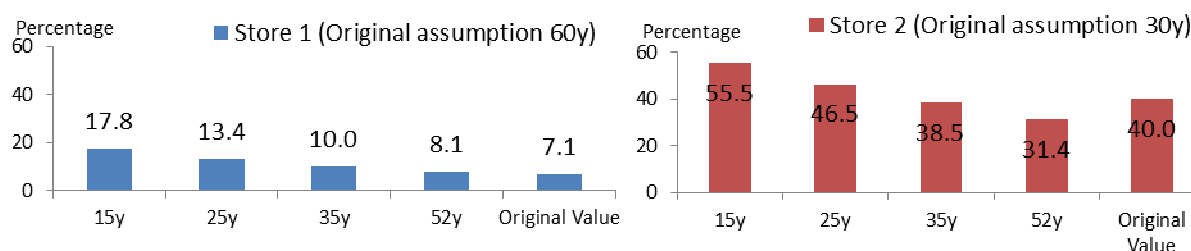


Figure 1: Impact of service life on calculated embodied carbon as a percentage of whole life carbon for two supermarkets

Compared to the original result, the embodied carbon proportion was higher in all but two of the eight modelled scenarios and in the case of Store 2, rose above 50% of whole life carbon emissions for the 15 year scenario. The proportional contribution of embodied carbon to whole life carbon increases as service life decreases: for store 1, there is an increase of 120%; and for Store 2 it is 77% between the maximum and minimum service life lengths assumed here. Thus the phenomenon described earlier whereby buildings with a more dominant operational phase are more sensitive to variance of the service life is clearly demonstrated.

### Discussion and conclusions

The results clearly highlight that the assumptions about service life length have a marked impact on ratio EC:OC. This is important because it calls into question assertions such as that of Scheuer et al., that ‘the optimization of operations phase performance should still be the primary emphasis for design’ [27, p. 1061]. Thus there is clearly a need for greater rigour in the justification of assumptions about service life. Of the three main options for justification found amongst published studies, design life is discounted on the basis that it is rarely a reliable indicator of the likely service life of a building. The proposed solution adopted here for the case study of UK supermarkets is to combine the remaining two approaches to use historic data from existing buildings as a basis for a parametric range for the service life.

There are drawbacks to this method, not least the requirement to gather significant amounts of data on existing buildings, which may be hard to obtain. Furthermore, drawing conclusions from the data was not straightforward in the case study presented. The data on existing stores is inconclusive as it cannot be proven how long these stores will last. Yet data on the store closures alone is not wholly representative, since a proportion of existing stores have already outlived the oldest store closure to date. Nevertheless, the research progress so far provides a good indication that the method has the potential to be developed in depth and breadth, leading to an improved understanding of the significance of different phases of the building lifecycle.

Further study of the technical and social factors that affect supermarket service life in practice could potentially allow for more case specific assumptions to be made for a given building. It could also lead to conclusions about how to minimise embodied impacts of supermarket construction, for example, if the non-technical aspects that limit service life can be mitigated. The technique should also be tested in other property sectors to ensure that it is applicable beyond the context demonstrated here of UK supermarket buildings.

### References

- [1] BIS, ‘Low Carbon Construction Action Plan - Government response to the Low Carbon Construction Innovation & Growth Team Report’. HMSO, London, 2011.
- [2] European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Roadmap for moving to a competitive low carbon economy in 2050*. 2011.
- [3] J. Anderson and J. Thornback, ‘A guide to understanding the embodied impacts of construction products’. Construction Products Association, 2012.
- [4] S. Sturgis and G. Roberts, *Redefining zero: Carbon profiling as a solution to whole life carbon emission measurement in buildings*. London: RICS Research, 2010.
- [5] RICS, *Methodology to calculate embodied carbon of materials: RICS information paper*. Coventry: Royal Institution of Chartered Surveyors, 2012.
- [6] M. Erlandsson and M. Borg, ‘Generic LCA-methodology applicable for buildings, constructions and operation services—today practice and development needs’, *Build. Environ.*, vol. 38, no. 7, pp. 919–938, Jul. 2003.

- [7] P. C. Kreijger, 'Environment, pollution, energy and materials', *Matér. Constr.*, vol. 6, no. 6, pp. 411–432, Nov. 1973.
- [8] A. Hallquist, 'Energy consumption: Manufacture of building materials and building construction', *Habitat Int.*, vol. 3, no. 5–6, pp. 551–557, 1978.
- [9] British Standards Institution, *ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines*. Geneva, Switzerland: International Standards Organisation, 2006.
- [10] N. Huberman and D. Pearlmutter, 'A life-cycle energy analysis of building materials in the Negev desert', *Energy Build.*, vol. 40, no. 5, pp. 837–848, Jan. 2008.
- [11] L. Gustavsson, A. Joelsson, and R. Sathre, 'Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building', *Energy Build.*, vol. 42, no. 2, pp. 230–242, Feb. 2010.
- [12] T. Ramesh, R. Prakash, and K. K. Shukla, 'Life cycle energy analysis of buildings: An overview', *Energy Build.*, vol. 42, no. 10, pp. 1592–1600, Oct. 2010.
- [13] British Standards Institution, *BS EN 15643-1:2010 Sustainability of construction works — Sustainability assessment of buildings Part 1: General framework*. London: British Standards Institution, 2010.
- [14] I. Sartori and A. G. Hestnes, 'Energy use in the life cycle of conventional and low-energy buildings: A review article', *Energy Build.*, vol. 39, no. 3, pp. 249–257, 2007.
- [15] L. F. Cabeza, L. Rincón, V. Vilariño, G. Pérez, and A. Castell, 'Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review', *Renew. Sustain. Energy Rev.*, vol. 29, pp. 394–416, Jan. 2014.
- [16] C. B. Aktas and M. M. Bilec, 'Impact of lifetime on US residential building LCA results', *Int. J. Life Cycle Assess.*, vol. 17, no. 3, pp. 337–349, Mar. 2012.
- [17] M. Suzuki and T. Oka, 'Estimation of life cycle energy consumption and CO<sub>2</sub> emission of office buildings in Japan', *Energy Build.*, vol. 28, no. 1, pp. 33–41, Aug. 1998.
- [18] O. F. Kofoworola and S. H. Gheewala, 'Environmental life cycle assessment of a commercial office building in Thailand', *Int. J. Life Cycle Assess.*, vol. 13, no. 6, pp. 498–511, Sep. 2008.
- [19] O. F. Kofoworola and S. H. Gheewala, 'Life cycle energy assessment of a typical office building in Thailand', *Energy Build.*, vol. 41, no. 10, pp. 1076–1083, Oct. 2009.
- [20] S. Xing, Z. Xu, and G. Jun, 'Inventory analysis of LCA on steel- and concrete-construction office buildings', *Energy Build.*, vol. 40, no. 7, pp. 1188–1193, 2008.
- [21] D. Densley Tingley, 'Design for Deconstruction: an appraisal', PhD, University of Sheffield, Sheffield, 2013.
- [22] T. Yashiro, H. Kato, T. Yoshida, and Y. Komatsu, 'Survey on real life span of office buildings in Japan', in *Proceedings, CIB*, 1990, vol. 90, p. W55.
- [23] R. J. Cole and P. C. Kernan, 'Life-cycle energy use in office buildings', *Build. Environ.*, vol. 31, no. 4, pp. 307–317, 1996.
- [24] R. Fay, G. Treloar, and U. Iyer-Raniga, 'Life-cycle energy analysis of buildings: a case study', *Build. Res. Inf.*, vol. 28, no. 1, pp. 31–41, Jan. 2000.
- [25] British Standards Institution, *BS EN 1990:2002+A1:2005 Eurocode. Basis of structural design*. London: British Standards Institution, 2002.
- [26] J. O'Connor, 'Survey on actual service lives for North American buildings', in *Woodframe Housing Durability and Disaster Issues Conference*, Las Vegas, 2004.
- [27] C. Scheuer, G. A. Keoleian, and P. Reppe, 'Life cycle energy and environmental performance of a new university building: modeling challenges and design implications', *Energy Build.*, vol. 35, no. 10, pp. 1049–1064, Nov. 2003.



## **A Comparative study of housing life-cycle carbon emissions for the characteristics of structural materials**

Ji-yeon Park<sup>1</sup>, Chang-u Chae<sup>2</sup>, Sung-hee Kim<sup>3</sup>

<sup>1</sup> Korea Institute of Civil Engineering and Building Technology, Republic of Korea

<sup>2</sup> Korea Institute of Civil Engineering and Building Technology, Republic of Korea

<sup>3</sup> Hanyang University, Republic of Korea

**Abstract:** *Buildings composed of various construction materials and components manufactured through various processes, induce enormous environmental pollution, such as global warming throughout the entire life cycle from production to disposal stages. In particular, cement, concrete and steel materials which are major construction materials constituting a building, are regarded as typical CO<sub>2</sub> generating materials and it is necessary to develop an alternative to those materials to reduce greenhouse gas. In the assessment, the LCCO<sub>2</sub> technique as an evaluation tool for life-cycle CO<sub>2</sub> emissions is adopted for the comparative analysis of the environmental impacts. Through the comparative analysis of the houses based on the evaluation results, this study attempts to identify potential carbon emission reductions from the reuse and reduction of housing materials and propose eco-friendly development potentials in the housing market.*

***Low Carbon Technology, Life Cycle Assessment, Green Building, Building materials***

### **1. Introduction**

#### **1.1. Background of the study**

While multi-faceted efforts for greenhouse gas reduction are being carried out worldwide, environmental measures have been advanced from various sectors in Korea to reduce greenhouse gas emissions. The greenhouse gas emissions in domestic construction sector accounts for about 40% of total emissions for material production and building management and various efforts for developing technologies are also being accelerated to reduce the emissions. In particular for building materials, concrete, cement, and steel materials are regarded as typical CO<sub>2</sub> generating materials and it is necessary to develop low-carbon materials or an alternative to those materials to reduce greenhouse gas. Also, for the sustainable and eco-friendly development of the construction sector, efforts should be made for eco-friendly material and technology development to reduce its environmental impacts.

#### **1.2. Necessity and purpose of the study**

This study intends to analyze modular houses that tend to increase in a compact housing market and conventional concrete houses from the perspective of LCA, and compare their environmental impacts generated throughout whole life cycle. A modular house is an industrialized house that can be mass-produced in the form of a unit in a factory and

prefabricated on site for being produced in large quantities for a short period. The modular house is designed with a prefabricated structure, allowing recycling and reuse of building materials through the assembly and dismantling of its structural members to reduce waste material. Besides, it has a number of advantages over conventional construction types including cost savings and site personnel reduction and a wide variety of configuration and styles in the building layout as a result of the lightweight construction and large supply of modular houses. Also, the modular house is expected to be effective in reducing materials and energy consumption compared to conventional construction types such as reinforced concrete structures, eventually reducing greenhouse gas emissions and the environmental impact.

Through the comparative analysis of the houses based on the evaluation results, this study aims to identify potential carbon emission reductions from the reuse and reduction of housing materials and to propose eco-friendly development potentials in the housing market.

## **2. Life cycle assessment (LCA) methodology for building**

### **2.1. Overview of LCA methodology for buildings**

In the assessment, environmental impacts are evaluated by comparing reinforced concrete structure houses to modular houses from the perspective of LCA. As an evaluation tool for environmental impacts of environmental burden materials that occur in the life cycle of products and systems, LCA is intended to evaluate quantitatively potential impacts associated with inputs and outputs generated from the life cycle of a product on the environment in the production, construction, use and disposal stages. Among the tools available to evaluate environmental performance, LCA provides a basic structure and principle to evaluate environmental performance and impacts on sustainable development by considering the potential environmental impacts from all stages of manufacture, product use and end-of-life stages, and as a result, to establish criteria for evaluating the environmental impacts in the building life cycle.

### **2.2. LCA methodology**

A building LCA includes setting a functional unit for a product system, providing a reference flow to which the inputs and outputs can be related, and system boundaries to define the scope of data collection for the product. An LCA starts with an explicit statement of the goal and scope of the study, and then sets the functional unit and reference flow.

The functional unit quantifies the function and scope delivered by the product to be assessed, setting the amount of product required for conducting the assessment. Further, the functional unit is set in consideration of the life time and performance of a target and the end user's perspective. Reference flow is also taken into account to set the functional unit for the comparative evaluation. The reference flow is determined by the final outcome necessary for the functional unit by identifying the process flow of a building. To develop a LCA, system boundaries for the life cycle of a product is to be defined. A clear definition is required for the system boundaries to be assessed and a clear explanation is required for the portion not to be assessed. The system boundary for the LCA of a building comprises all unit processes from

the entire life cycle to be evaluated, including raw material extraction, transportation and product manufacturing stages.

The unit process included in a system boundary is referenced based on the inputs and outputs in a system boundary. Because raw materials, products and energy that are inputted vary with the unit process of the life cycle, data categories are chosen to collect input and output data. If recycled·reusable materials are to be reintroduced to the process within a system boundary, reuse·recycling processes are included in the system boundary for evaluation. Using the corresponding LCI DB module on the basis of the calculation formula of the data, collected data are multiplied by a greenhouse gas emission factor to calculate the greenhouse gas emissions for each data set. Carbon dioxide emissions per data to be calculated include the amount of carbon dioxide emissions in each stage of the life cycle and the one emitted during the life cycle of the building.

### 3. Overview of assessment targets and assessment methods

#### 3.1. Overview of assessment targets

The buildings to be compared include a reinforced concrete apartment house and a modular house. The reinforced concrete apartment house uses a electric boiler heating system in 98 square meters with a 4-person household. The modular house with for a 1-person household uses an electric boiler heating system in a unit type prefabricated structure.

Type	R.C. Apartment Housing	Modular Housing
Building type	Apartment Building	Modular Unit
Area	98 m <sup>2</sup>	22 m <sup>2</sup>
Number of occupants	4 persons	1 person
Heating system	electric boiler	electric boiler
Heating energy usage	54 kwh/m <sup>2</sup> ·year	49kwh/m <sup>2</sup> ·year

*Table 1 Overview of target buildings*

#### 3.2. Assessment methods

For the houses to be compared that differ in housing area and number of occupants, the basis of comparison for analysis results is required.

For the LCA analysis in this study, greenhouse gas emissions during the life cycle are analyzed from one household house. In the case of a modular house, because the life-span of a house varies with the materials used, it is difficult to define the life cycle of the house. Thus, in consideration of the service life of a concrete building, the life cycle was set to 30 years. The reference flow was set for the analysis on the amount of energy and materials that are inputted in the production, construction, use, and disposal stages of a one household residential building to be used for 30 years.

The system boundaries for the reinforced concrete house and modular house are set differently in the production and construction stages of LCA, For the reinforced concrete house, the production stage includes material production and all the processes before materials are delivered to the construction site after processed, and the construction stage

comprises the processes in which materials are transported to the construction site and a house is built. The processes of house repair·maintenance and energy usage by residents are included in the use stage. The disposal stage is associated with the amount of energy of equipments caused by house dismantling and waste material transportation, and all the processes for the reuse of waste materials, recycling, incineration and landfill.

To conduct a LCA, the data of the raw materials and transportation of the life cycle is calculated by setting a scenario. Data is calculated within the range that does not affect the evaluation results. The scope of data collection is typically determined by 95% or 99% of the cumulative mass contribution. For this assessment, the materials corresponding to 99% of the cumulative mass contribution are used for data calculation.

For this assessment, the top-down approach is chosen to determine the data values by reducing the unit of comparison targets. For the criteria that can compare by quantifying targets, data is compared by setting a comparison unit for area and number of occupants, eventually, for emissions per household, unit area, and person.

## 4. Analysis of life cycle carbon emissions

### 4.1. Life cycle CO emissions

The analysis results of the life cycle total emissions showed the modular house generated emissions of 39,375kgCO<sub>2</sub>eq when using general materials and 37,976kgCO<sub>2</sub>eq when using reusable·recycled materials. For the reinforced concrete house, the emissions were 113,321kgCO<sub>2</sub>eq from general materials and 90,798kgCO<sub>2</sub>eq from reusable·recycled materials.

Type		Emissions				Total emissions
		kgCO <sub>2</sub> eq/household·30years	kgCO <sub>2</sub> eq/m <sup>2</sup> ·30years	kgCO <sub>2</sub> eq/person·30years	%	kgCO <sub>2</sub> eq/person·30years
Modular house using general materials	Production stage	6,413	292	6,413	16.3	39,375
	Construction stage	110	5	110	0.3	
	Use stage	32,820	1,492	32,820	83.4	
	Disposal stage	32	1	32	0.1	
Modular house using reusable·recycled materials	Production stage	5,014	228	5,014	13.2	37,976
	Construction stage	110	5	110	0.3	
	Use stage	32,820	1,492	32,820	86.4	
	Disposal stage	32	1	32	0.1	
Reinforced concrete house using general materials	Production stage	233,475	2,382	58,369	51.5	113,321
	Construction stage	6,086	62	1,522	1.3	
	Use stage	197,505	2,015	49,376	43.6	
	Disposal stage	16,217	165	4,054	3.6	
Reinforced concrete house using recycled materials	Production stage	143,383	1,463	35,846	39.5	90,798
	Construction stage	6,086	62	1,522	1.7	
	Use stage	197,505	2,015	49,376	54.4	
	Disposal stage	16,217	165	4,054	4.5	

Table 2 Total carbon emissions by stage during life cycle

### 4.2 Comparative Analysis

From the perspective of LCA, the carbon emissions of a reinforced concrete house and a modular house were compared and analyzed for each stage, based on the life cycle of 30 years and one household. Life cycle greenhouse gas emissions were analyzed and eventually a comparative analysis was applied by dividing into emissions per unit area and per person.

Type	Total emissions					
	kgCO <sub>2</sub> eq/ household · 30years	Reductions against RC house using general materials	kgCO <sub>2</sub> eq / m <sup>2</sup> · 30years	Reductions against RC house using general materials	kgCO <sub>2</sub> eq/ person· 30years	Reductions against RC house using general materials
Modular house using general materials	39,375	413,908	1,790	2,835	39,375	73,945
Modular house using reusable-recycled materials	37,976	415,307	1,726	2,899	37,976	75,344
Reinforced concrete house using general materials	453,283	0	4,625	0	113,321	0
Reinforced concrete house using recycled materials	363,191	90,092	3,706	919	90,798	22,522

*Table 3 Comparison of carbon emissions during life cycle*

#### (1) Comparative analysis of emissions per household

The comparative analysis of life cycle carbon emissions showed that the total carbon emissions of the modular house was 39,375kgCO<sub>2</sub>eq per household when using general materials and 37,976kgCO<sub>2</sub>eq when using reusable-recycled materials. The reinforced concrete house using general materials showed the total emissions of 453,283kgCO<sub>2</sub>eq, indicating the modular house was more effective by more than 80% in reducing the emissions than the reinforced concrete house. Further, the emissions from the reinforced concrete using reusable-recycled materials were reduced by more than 20%, compared to the reinforced concrete house using general materials.

#### (2) Comparative analysis of emissions per unit area

The analysis results of the life cycle total emissions per unit area for 30 years showed the reinforced concrete house using general materials generated emissions of 4,625kgCO<sub>2</sub>eq. Also, the emissions from the modular house were 1,790kgCO<sub>2</sub>eq when using general materials and 1,726kgCO<sub>2</sub>eq when using reusable-recycled materials. It is also shown that the total emissions of the modular house were reduced by approximately 60% compared to the reinforced concrete house.

#### (3) Comparative analysis of emissions per person

The comparative analysis of life cycle carbon emissions per person showed that the total carbon emissions of the reinforced concrete house was 113,321kgCO<sub>2</sub>eq per person when using general materials and 90,798kgCO<sub>2</sub>eq per person when using reusable-recycled materials. The modular house showed the total emissions of 39,375kgCO<sub>2</sub>eq per person for using general materials, and 37,976kgCO<sub>2</sub>eq for using reusable-recycled materials. This indicates the modular house with reusable-recycled materials was more effective by approximately 66% in reducing the emissions than the reinforced concrete house. Further, the emissions from the reinforced concrete with reusable-recycled materials were reduced by approximately 20%, compared to the reinforced concrete house with general materials.

### 5. Analysis of assessment results



From the perspective of LCA, the carbon emissions of a reinforced concrete house and a modular house were compared and analyzed in each stage. Depending on the assessment method, the life cycles of 30 years for two houses to be compared were divided into production, construction, use and disposal stages to collect data, and the emissions were calculated by using an emission factor.

From the results regarding major environmental impact factors in the life cycle of each evaluated house, it was analyzed that the outputs of concrete in the production and construction stages of the reinforced concrete house, gas usage by heating in the use stage and the amount of recycled waste concrete in the disposal stage were major environmental impact factors. For the modular house, the amount of steel frame and plasterboard was regarded as a major environmental impact factor in the production stage, but the emissions were significantly reduced when reusable and recycled steel frames were used. In the use stage, electricity usage by using an electric furnace, and the carbon emissions due to the landfill of materials in the disposal stage were regarded as major environmental impact factors.

However, it was analyzed the reduction of outputs due to the reuse of materials in the disposal stage exerted the greatest effect on the reduction of emissions. It is shown that the modular house using general materials can reduce the emissions by 413 tons over 30 years, compared to the reinforced concrete house with general materials, and the modular house with reusable-recycled materials can reduce the emissions by 415 tons. The modular house with reusable-recycled materials is shown to be more effective in reducing 415 tons of greenhouse gas emissions over 30 years than the reinforced concrete house with general materials, which is equivalent to the amount of carbon dioxide that 28,000 30-years old pine trees absorb for one year.

When using these modular houses for 90 years, it is expected that 1,200 tons of greenhouse gas emissions can be reduced, as compared to reinforced concrete houses with general materials. Therefore, by the improvement of the performance of modular houses resulting from future performance development of modular houses and the introduction of energy-saving technologies, potential reduction is expected to be larger.

## 6. Conclusions

In this study, to reduce greenhouse gas in the life cycle of a building, we analyzed the environmental performance due to building materials by comparing and assessing the life cycle of a reinforced concrete house and a modular house to provide the direction of eco-friendly development of building materials.

A LCA was applied to the reinforced concrete house using general concrete materials and a recycled material of slag concrete, and the modular house using general materials and reusable-recycled materials, to compare their environmental impacts arising from the use of reusable-recycled materials. The analysis results of life cycle carbon emissions per person over 30 years showed that the total carbon emissions of the reinforced concrete house was 113,321kgCO<sub>2</sub>eq when using general materials and 90,798kgCO<sub>2</sub>eq per person when using



reusable-recycled materials. Further, the emissions from the use of a recycled material of slag concrete were shown to decrease by approximately 20%, compared to the use of general materials. The modular house showed the total emissions of 39,375kgCO<sub>2</sub>eq per person over 30 years for using general materials, and 37,976kgCO<sub>2</sub>eq for using reusable-recycled materials, resulting in a reduction of carbon emissions by 1.4 tons. This indicates the modular house with general materials was more effective by approximately 65% in reducing the emissions than the reinforced concrete house. Factors affecting the emissions of greenhouse gases appeared slightly different in the two types of house. The use of concrete and rebar in the production of the reinforced concrete house and gas usage by heating in the use stage were shown to be major environmental impact factors. For the modular house, steel frame and plasterboard in the production stage and electricity usage in the use stage were regarded as major environmental impact factors. Difference in the heating system in the use stage was also found to affect the difference in greenhouse gas emissions. It is also found that the reuse or recycling of building concrete and steel materials is capable of reducing greenhouse gas emissions in the production stage.

Further, modular houses are expected to contribute more actively to environmental protection and resource saving compared to existing reinforced concrete houses, by reducing the emissions and relatively reducing energy consumption in the production stage from the environmental aspect related to the response to climate change. However, there is a weakness of modular house, such as fire safety performance and durability as compared to conventional reinforced concrete buildings, and it is necessary to solve the technical challenges including noise and indoor environment to address the need for technology development associated with performance improvement. As a result, it is needed to consider the development of a building that can reduce the environmental impact by applying the modular housing method to slag concrete and complementing its performance and safety.

In future, ongoing technology development and research of building materials complemented with environmental advantages are essential to cope with climate change and reduce an environmental impact.

## References

- Seol Dongpil, (2012), A study on the efficiency of housing supply policy with increasing of 1~2 person household, Seoul
- Kim Gyuntae et al, (2011), Scenario development of Korean modular house construction, Architectural Institute of Korea
- Heo SungHoon et al, (2011), A study on the small sized housing supply according to the changes in family composition, Architectural Institute of Korea
- Heo Tak et al, (1995), Principle of life cycle assesment, Korea employer's federation



## Development of a new type of HEMS (Home Environment and Energy Management System) for cohousing

Nakajima, Y

Associate Professor, Kogakuin University, Tokyo, Japan

**Abstract:** *Technologies such as home energy management systems are being developed as energy-conservation measures in the home sector. However, since past systems have focused mainly on displaying amounts of energy consumption, it has been difficult to direct attention to efforts related to the environmental performance of homes themselves and to comfortable ways of living. At the same time, the number of home designs incorporating passive technologies is increasing, and it is important that residents put these technologies to full use.*

*This study developed a new type of HEMS and incorporated it into an environmentally friendly cohousing residence, as a system making environmental and energy conditions visible. It was intended to raise awareness of the environment among residents by displaying various information. As a result, frequency of actions for improvement of comfortability has increased by checking data of display in some families.*

***Energy-conservation, HEMS, Awareness, Information, Lifestyle, Cohousing***

### 1. Introduction

Technologies such as home energy management systems (HEMS) that make energy use visible are being developed as energy-conservation measures in the home sector, as intangible factors have come to be recognized as important in promoting energy-conserving lifestyles. However, since past systems have focused mainly on displaying energy consumption, attention has focused on energy-conserving equipment. It has been difficult to direct attention to efforts related to the environmental performance of homes themselves and to comfortable ways of living. At the same time, the number of home designs incorporating passive technologies is increasing, and it is important that residents put these technologies to full use.

In this study, we developed a new type of HEMS, as a system making environmental and energy conditions visible. It was intended to raise awareness of the environment among residents by displaying information on subjects such as temperature and humidity inside and outside the home, comfort, and energy consumption. Furthermore, this system, built for use in cohousing, makes it possible for residents to compare information on their own residential units with that of other units. We incorporated this system into an environmentally friendly cohousing residence (the “residence” hereinafter) and attempted to verify its results.

### 2. Overview of the Residence

Table 1 shows an overview of the residence, and Figure 2 shows a floor plan and exterior. The residence is a cohousing terrace house completed in February 2011 in the city of Sagami-hara, Kanagawa Prefecture, Japan. Constructed as a cooperative, it is owned by four households. It consists of four buildings belonging exclusively to the individual households (buildings B, C, E, and F) in addition to a common house (Building A) and a storeroom

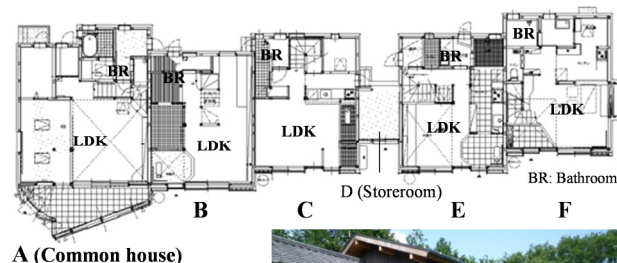
(Building D), both jointly owned. The common house, equipped with facilities including a spacious living room, a dining room, and a kitchen, serves as a place where the residents can eat and meet with each other. Its other uses include serving as a guest room and hosting community events involving the residents.

Since there the residents changed in Building B in the winter of 2012 and in the spring of 2014, and in Building C in the spring of 2014, this study's analysis is centered on buildings E and F, for which there has been no change in occupants since completion of the residence. Through 2013, the residence had the following occupants: three persons (a married couple and one parent) and then two persons (a married couple) in Building B, four persons (a married couple and two children) in Building C, one person (a male) in Building E, and two persons (a married couple) in Building F. The head of household in each unit was aged in his or her 30s or 40s.

The residence also uses numerous natural materials such as solid natural wood, stone, and earth together with a passive design incorporating natural ventilation, heat exhaust, direct gain, and nighttime thermal purging through skylights and earthen walls. The building is said to enable improvements in the heat environment and energy conservation through its residents putting these passive methods to effective use (passive behavior). One characteristic of its facilities is the lack of air-conditioning in all units, while various types of room heaters are used for heating.

*Table 1. Overview of the residence*

Location	Sagamihara City, Kanagawa Pref., JAPAN
Established in	February, 2011
Structure	Two storied wooden building
Number of apartments	4houses + common house
Number of residents	1 to 4 per apartment
Total floor area	378 m <sup>2</sup>
Hot water supply system	Gas hot water heater
Cooling equipment	Not included
Heating equipment	Oil heater, Pellet stove, Wood stove



*A (Common house)*

*Figure 1. Floor plan and Exterior*



### 3. Overview of this New Type of HEMS

#### 3.1. System Concept

While most HEMS systems currently in existence encourage energy-conservation behavior by residents through displaying the power consumed by home appliances, the new type of HEMS in this study is intended to improve the interior heat environment and conserve energy by encouraging appropriate passive behavior among residents through displaying easily understandable information on subjects such as interior and exterior atmospheric conditions and heat environmental conditions. Its other results are expected to include the sharing of information on daily system use and on passive behavior and raising awareness of energy conservation through incorporating a screen that makes possible comparisons among households and a function similar to a bulletin board, utilizing the distinguishing features of this property as a cohousing residence.



### 3.2. System Overview

Figure 2 shows examples of screens displayed. The system measures the following items: exterior atmospheric conditions (temperature and humidity, solar radiation, wind direction and speed, and precipitation), power consumption on each residential unit's circuit (up to a maximum of 24 circuits), gas consumption, water consumption, temperature and humidity in the main rooms, wall and floor surface temperatures, and whether the skylights and curtains are open or closed. Measurements are taken at 10-minute intervals, and data on power and whether skylights and curtains are open or closed is updated largely in real time. The system uses the measurement instruments' wireless communication features and a Wi-Fi network to transmit these measurement data to a server in Building A, which processes the data into easily understandable graphs and other formats and then makes it accessible, together with various types of advice and living information, from personal computers and tablets via a homepage exclusively for use by residents. Each resident household is issued one tablet.



Figure 2. Examples of screens displayed

The main characteristics of this system are its Interior Environment screen, its My Home Now screen, and its Household Comparison screen. On the Interior Environment screen, users can view simultaneously graphs of changes in interior temperature and humidity, exterior atmospheric conditions, whether skylights and curtains are open or closed, and power consumption. On the My Home Now screen they can view in real time whether curtains and skylights in each building are open or closed, interior temperature and humidity, wall and floor temperature, and power consumption by circuit. The Household Comparison screen displays side-by-side power, gas, and water consumption and interior environmental data for each building, intended to encourage exchange of information among the residential units. All of the above screens provide environmental information intended to support residents' efforts to put the building to good use. The system also features a calendar screen on which users can enter their plans and a living information screen showing weather information and train and bus schedules. This system was nicknamed Terrace House Kawaraban after the kawaraban commercial newssheets of the Edo Period in Japan, since it was intended to serve as a system that provides a variety of information closely related to residents' lives.

The system went into operation in August 2012, about one and one-half years after the completion of construction. This was timed so that residents could evaluate various matters from both before and after use of the system began. Measurement of data and surveying of residents began at the time construction was complete. In summer 2013 the system's functions and display content were upgraded to incorporate requests from residents.



#### 4. Screen Viewing

Figure 3 shows changes over time in viewing of the system's screens by the three households other than that in Building B, where there was a change in occupants soon after use of the system began. (Building C was vacated in June 2013.) A look at changes over the course of the year shows that numbers of views tended to increase during the summer and winter and to decrease in spring and autumn. It would appear that interest in environmental information increases during the hot and cold seasons. There also was an increase apparent after the system upgrade in summer 2013.

Figure 4 shows a breakdown of screens viewed by type. A look at the results for Building E shows that the share of views accounted for by the electric power graph increased beginning in the summer of 2013, while during winter the share for environmental information rose. This likely was affected strongly by the addition of display of the pace of electricity use and a humidity graph in the system upgrade. For Building F too, the shares accounted for by views of environmental information were relatively higher in the summer and winter seasons. In addition, the numbers of views of the calendar page show an increasing trend even though that page was not upgraded. This was due to an increase in the frequency of use of the Common Calendar page for the four households, indicating that the system is playing a role in the formation of a community among the households.

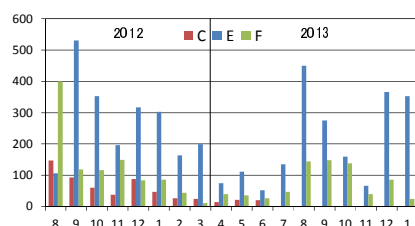


Figure 3. Monthly frequency of screen viewing

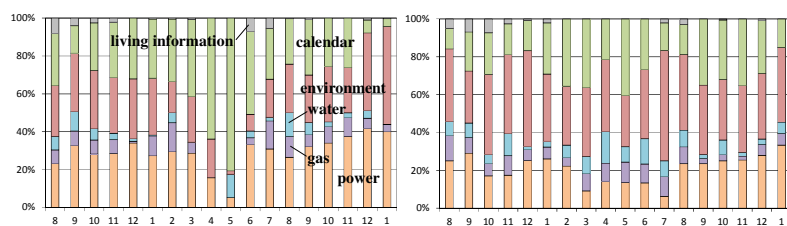


Figure 4. Ratio of frequency of screen viewing by type  
(left: Building E / right: Building F)

#### 5. Verification of Heat Environment Adjustment Behavior

##### 5.1. Examples of Encouraging Passive Behavior

The residence uses numerous earthen walls, which have large thermal capacities. During the summer it purges heat through nighttime ventilation, while it is expected to accumulate heat through direct gain during the winter. Figure 5 shows a graph of the heat environment on typical days when the effects of nighttime thermal purging were used. On August 20 the windows and curtains were left open all day from the previous evening, while on August 21 the windows and curtains that had been left open from the previous evening were closed in the morning. A look at this graph shows that while the temperature of a room on the first floor had fallen to 22°C by dawn on both days, the highest room temperature during the daytime was 28°C on the 20th but was 1.4°C lower on the 21st. Similarly, the second-floor room temperature was 2.2°C lower, wall temperature 2.1°C lower, and floor temperature 5.3°C lower, showing that the effects of nighttime thermal purging can be maintained by closing the windows in the morning. The log of views of the interior environment screen shows that the

system was viewed intermittently on the night of the 20th and on the morning and early evening of the 21st, and from this information the system can be surmised to have facilitated residents' senses and understanding of passive behavior.

## 5.2. Passive Behavior in the Summertime

Next we will analyze changes over the years in passive behavior, over the period from 2011 through August 2013. We summarized numbers of days residents spent at home all day ("days home all day"), numbers of effective passive behavior actions on days home all day, and numbers of days on which residents viewed the system as part of effective passive behavior actions on days home all day. Days home all day were determined based on energy consumption and other data. Effective passive behavior was defined as passive behavior conducted in a manner timed to match the conditions displayed as part of the passive behavior advice provided by the system.

Since in 2011 the system had not yet been adopted and residents' understanding of passive behavior was low, they used effective passive behavior on only six days even though they had been home all day on 17 days (35%). While understanding still was weak in 2012 since it was right after adoption of the system, the effective number of days they used effective passive behavior of four reflected an increase in percentage terms (40%). In 2013 the percentage increased further, with a number of days of three (75%). From a look at residents' viewing of the system, it can be surmised that they were using the system as a reference for their passive behavior.

Figure 6 shows changes over the summer season (July through September) from 2011 through 2013 in the highest air temperature and in the highest air temperature minus the highest room temperature on the first floor. These data show that in 2012 and 2013 both buildings E and F maintained lower room temperatures even though the highest air temperatures were higher than in 2011. While these results may be related to changes in the ways residents stayed home, it is conceivable that they were affected even more strongly by the higher frequency at which the residents effectively employed passive behavior.

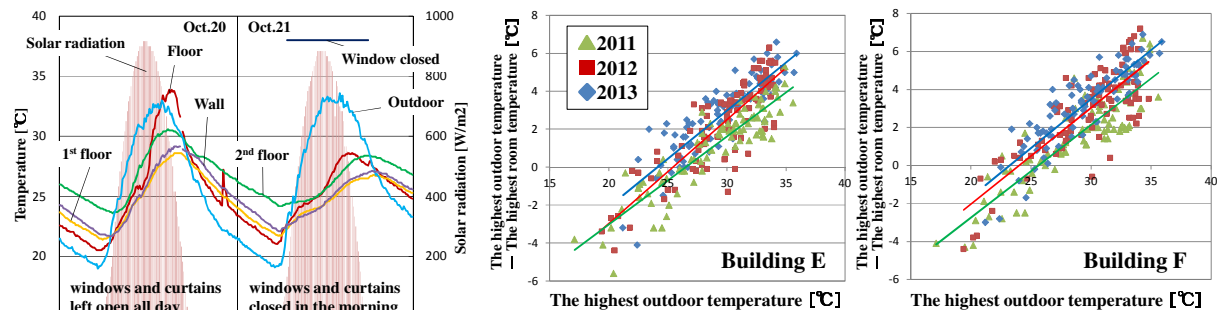


Figure 5. Effects of nighttime thermal purging

Figure 6. Changes of indoor-outdoor temperature differential

## 5.3. Humidity Environment Adjustment Behavior in Wintertime

Figure 7 shows a histogram of room humidity only during the times residents were home in December from 2011 through 2013, for buildings E and F. Figure 8 shows a graph of

humidity data ranked from high to low, by year. Since Building E used a wood-burning stove for heating, it tended to dry out. In particular, Building E's humidity was low overall in 2011, frequently at 40% or lower, but its humidity shows an improving trend from year to year, so that in 2013 it was lower than 40% only about one-fourth of the time. In addition, since as described above the rate of viewing the environmental information screen increased in December 2013, it is conceivable that the addition of a humidity graph in the system upgrade may have had an effect as well. Like Building E, Building F also showed an improving trend from year to year, implying that residents' awareness of room humidity has increased. The graph shows that in 2013 the room humidity almost never fell below 40 percent.

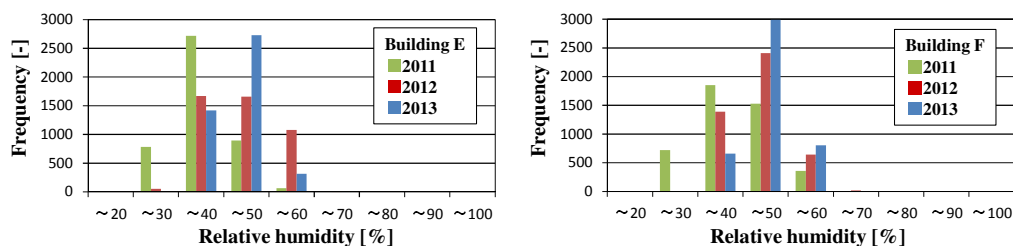


Figure 7. Histogram of room humidity

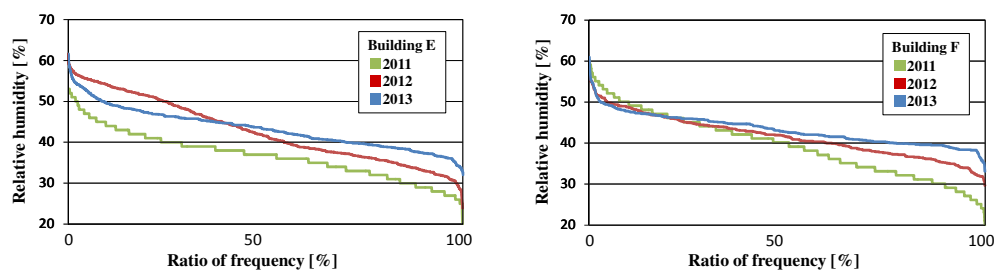


Figure 8. Ratio of frequency of room humidity

## 6. Changes in Energy Consumption Over the Years

Figure 9 shows changes in power consumption in the three households from 2011 through 2013, while Figure 10 compares the power consumption of buildings E and F between the summer (July through September) and winter (November through January). Since numbers of days at home vary by year, figures have been converted to consumption per day for comparison purposes. Building E shows a decreasing trend in both summer and winter. Consumption of power from power outlets is decreasing in particular. No major changes were apparent in Building F. While its use of power from power outlets increased somewhat during

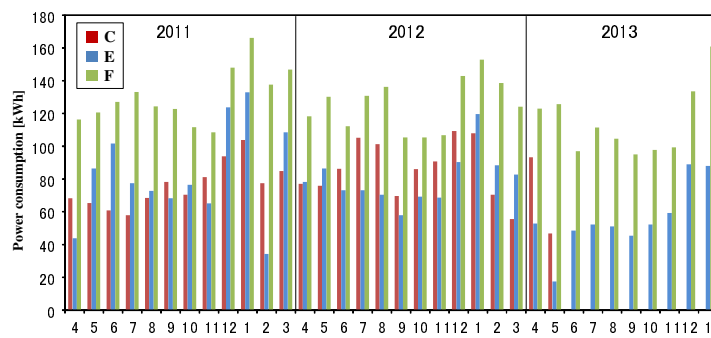


Figure 9. Changes in power consumption

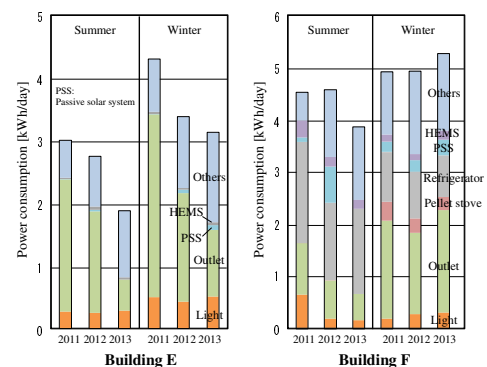


Figure 10. Effect of the energy conservation



the winter of 2013, this is thought to be a result of use of humidifiers and other equipment to the humidity environmental conditions. Neither Building E nor Building F showed any decreasing or increasing trend in consumption of gas or water, which was affected strongly by residents' lifestyle. Since these households consumed substantially less energy than the average household from the start, it is unlikely that any marked decreases would occur, but still there can be said to be room for system improvements toward reducing consumption.

## 7. Conclusions

This study developed a new type of HEMS intended to encourage appropriate passive behavior among residents and to improve interior thermal environment and conserve energy, by displaying in easily understandable ways interior and exterior environmental conditions and other information. The main findings from the study are outlined below:

- Examples were confirmed of use of the system in implementing practical passive behavior.
- From analysis conducted over a period of approximately one and one-half years following adoption of the system, it was confirmed that the system was used continually, centered on the interior environment screens, and that the system upgrade during this period had an effect.
- Use of the system was surmised to have had an impact on passive behavior, as temperature settings in the summer and humidity settings in the winter improved to more comfortable ranges.
- While many of the households studied originally consumed considerably less energy than the average household, some households showed further reductions in consumption following adoption of the system.
- While no improvements in interior environmental conditions or energy conservation effects from use of the system as a means of cohousing could be identified, the house Common Calendar was used highly frequently, and it can be considered to be contributing to community formation.

One topic for future study is that of increasing the system's multiplicity of uses to help it find acceptance by the general public. Future plans call for proceeding with studies of how to design a system with consideration for various distinctive properties of residents, such as their age ranges, lifestyles, and levels of environmental awareness.

## Acknowledgements

The author expresses appreciation to Mr. Jun Yuasa, Ms. Mayu Sekino, Mr. Takahiro Yamada, Eeyes corporation and all of the residents in the cohousing. This study was partially supported by The Asahi Glass Foundation.

## References

- 1) Yuasa, J., Sekino, M., Nakajima, Y. (2013) Research on the indoor environment and lifestyle in the suburbs type cohousing using natural materials Part4, Summaries of technical papers of Annual Meeting Architectural Institute of Japan. D, pp.539-540
- 2) Kido, H., Nakajima, Y. (2012) Predicted energy conservation by use of common areas in cohousing, International Journal of Sustainable Building Technology and Urban Development, Volume 3, Issue 3, pp.177-184
- 3) Nakajima, Y., Sato, K., Noudomi, A. (2010) Development of the environment and energy information system in residential house, AIJ Journal of Technology and Design Vol.16 No.34, pp.1069-1074

## The non-use of sustainability performance tools

Forman, Marianne <sup>1</sup>; Haaugbølle, Kim<sup>1</sup>;

<sup>1</sup> Danish Building Research Institute/Aalborg University, Copenhagen, Denmark

<sup>2</sup> Danish Building Research Institute/Aalborg University, Copenhagen, Denmark

**Abstract:** *Energy retrofitting has been a key issue in recent years due to the general focus on climate change and the Danish government's target of reducing CO<sub>2</sub> emissions from buildings by 2050. Case studies of two web-based tools are used to examine how web-based tools emerge and are used when property managers and consultants (architects and engineers) are challenged by new energy performance requirements for existing buildings. Web-based tools reflect the consultants who develop the understanding of how new problems can be solved and strategies to solve the problems. The further use and embedding of the tool depends on how it interacts with other actor strategies, e.g. legislation, and contributes to the current execution of tasks. This may influence the practice of property managers and do not necessarily reflect their long-term needs. The findings are important for the increasing focus on energy performance of existing buildings and property managers' need for establishing adequate practices.*

### **Energy performance, Digital tools, Construction, Energy retrofitting**

#### **Introduction**

Improving the energy performance of the existing building stock is perceived as a central part of the solution to climate change and the construction industry plays an important role in the transformation process. Energy strategies as reflected in the Danish Building Regulations have changed character and overall, one can describe the evolution as a shift from prescriptive regulations to performance-based regulations. Over the years, financial support has been given to the development of a number of sustainable calculation tools, websites, etc. in order to help construction clients and consultants to reduce energy consumption in existing buildings. New political agendas create a need for new ways to understand and coordinate data and affect the interaction between the actors involved in the translation and implementation in practice. In this way, the development of digital tools can be interpreted as proposals for new ways to coordinate data and structure practice.

The presented research is based on a qualitative approach in its aim to build understanding from empirical data. These data were collected in spring 2014. This research is based on two case studies of two web-based tools. The first tool is a tool to help consultants develop energy concepts for buildings, while the second tool aims at supporting the target-setting process of the construction client. Both tools have been developed to be used in the initial screening of the potential of buildings before the actual retrofitting project. Both tools were initiated as projects related to the increased focus on energy retrofitting and the new challenges that the actors faced in connection with the initial thinking on what measures would be appropriate to implement. The tools therefore combine in different ways energy





initiatives, economic considerations and the importance of the energy initiatives for the energy label of the building. In both cases, strong financial support was received for the development of the tools and the development was carried out by knowledgeable and well-recognised actors.

The increasing policy focus on energy optimisation of building operation and energy retrofitting of existing buildings forces the property managers to reorganise organisations as well as digital infrastructure in the organisation towards closer relationship between planning -, refurbishment - and operation of large building portfolios. This shift in perspective is also visible in the ongoing debates about whether the concept of "operational durability" can be used at the design stage. This paper focuses on major property owners or property managers, including governmental, private, regions and municipalities. In the following text, only property manager is used to describe this role. In a situation where the property manager acts in the role as client, client is used. Unlike traditional industry, the dominant mode of production in construction is project based, where design, planning and execution are carried out by project-based businesses. As a consequence, the construction sector is often defined by its project-based nature, and innovation in the construction sector is usually to be understood on the project's premises. In this paper, we aim to understand how web-based tools emerge and are used and their impact on practices within and between project-based companies and major property managers. A specific focus is put on innovation mechanisms that are embedded in this process and their impact on the result. This paper builds on the hypothesis that the relationship between developed digital technologies in the construction industry and the importance for the restructuring of major property managers' organisations and digital infrastructure towards integration of planning, refurbishment and operation is not sufficiently elucidated. Existing analysis of digital technologies' impact on construction are based on case studies of construction projects and focus on the effects of implementation of digital technologies on practices, processes, systems and the technologies themselves (1), the problem of digital methods to cross knowledge boundaries between different disciplines (2) and the importance of professionalism in digitally mediated projects (3). Firstly these perspectives introduce digital technologies as artefacts that already exist and secondly they all focus on project-based companies and not on clients. Therefore, there is a lack of knowledge about how digital technologies emerge as part of project-based companies' practices and how they (if they do) stabilise and structure new practices in both their own and property managers' organisations.

## Theory

In STS, the social shaping of technology approach relates to technological development and change as socially shaped and designed, and attention is given to the innovative agency of actors in the dynamics of technology development. Core concepts are relevant social groups, problems and solutions, technological frames and interpretative flexibility (4,5). The actors / relevant social groups participate in a forming process by identifying problems and developing solutions interpreted through the groups' respective technological frame.

Innovation is constituted by a technical frame that defines the specific technology/artefact as

well as the actors. The technical frames include artefacts as examples, actors with their competences, methods, key problems, solution strategies, practice, test procedures, design methods etc. Technical frames both guide social shaping processes and are also the result of social shaping processes and transformations. Closure and stabilisation can be perceived as two processes running concurrently in a technological development. Closure relates to the mechanisms that lead to a reduction of interpretative flexibility between relevant social groups as well as a reduction of the number of variables. Stabilisation relates to what is under construction and is thus a structural concept that focuses on what binds the constructed together and affect the actors as structures in the form of established networks, developed practices, etc. The technological frame ties closure and stabilisation processes together. It characterises the relationship between actors and artefacts and after stabilisation it will guide the actors. Different researchers have used the STS approach to analyse the importance – and use of digital technologies in constructions projects. However, the studies have limited the analyses from understanding the emergence of digital technologies. Chris Harty highlights with the notion “unbounded innovations” how innovations such as 3D CAD are taken into use at project and inter-organisational levels in construction. He distinguishes between bounded and unbounded innovations to differentiate between innovations where effects and consequences are related within a single organisation or inter-organisationally, respectively. He found that digital technologies are not finalised, fixed objects that can be implemented in a construction project and to which people must adapt “, *but are malleable and can be transformed through contests over the building of systems. Unforeseen consequences are also considered, where attempts at alignment can result in the exclusion of necessary actors from the system, and trigger the assembly of alternate, parallel systems*” ((1), p 521).

Neffs et al. (2) have investigated the importance of digital systems for communication, coordination, knowledge sharing and work processes. The desire to increase coordination and knowledge-sharing through digital systems between the actors of construction is confronted by the same actors’ need to adapt systems to their own practices. Experience suggests that the interpretative flexibility is reduced in shared digital systems so that individual professions are limited in their opportunities to exercise professionalism in undertaking their tasks. Neffs et al. (2) suggest that several factors affect how different communication technologies are used. These include i.a. different cognitive patterns between professions and differences in contractual arrangements. Jaradat et al. (3) have investigated how digitally mediated project work influences professionalism in the construction projects. The increased professionalisation of large construction clients affects the relationship between the professions within the traditional building process. New ways to approve construction projects and monitor processes are associated with the establishment of new professions (financial controllers etc.), new types of accountability of professions and increased integration across professions. However, this means that new types of conflicts arise where different professions have different understandings of project assignments and how they are competently to be achieved. The question then becomes whether it is content (construction related) or format (documentation related), which is the essential criterion for success. Furthermore the experience point to the fact that today the

increased focus on digital systems results in a tendency that it is the requirements of the digital systems that design the construction organisation rather than the other way around. Following their study, they point out that there is a need to explore more deeply how the correlation between the physical building and the digital building models / databases as digital models and databases play an increasingly important role in construction. At the same time, they point out that clients traditionally have construction management skills to manage cooperation within the team, but has so far lacked skills to manage digital processes and to construct databases.

### **Research setting and methods**

This research is based on paradigmatic studies of two web-based tools and data were collected in spring 2014. The case studies are examples of an information-oriented selection in contrast to the random selection, where the goal is to maximise the usefulness of information from individual cases. The selection of cases are based on the expectation of their information content. Strategic considerations above information content of the selected cases may therefore strengthen the reliability and validity of the study by clarifying what is special about the selected cases and what types of knowledge that it may therefore be reasonably to produce by means of case studies (6).

The paradigmatic case is when you want a case to serve as a model, a prototype or a metaphor for the area that the case concerns. The concepts of the tools were formulated respectively in 2006 and 2008 in a setting, where energy retrofitting was a growing theme in the construction sector. Energy Certification was introduced due to EU and Danish regulations and there was an increasing political attention towards changing frame conditions that could promote energy retrofitting. There was a common impression that energy retrofitting was fragmentary and that knowledge-sharing and joint strategy for the area was needed. There was a common understanding that overview and knowledge of technical solutions to reduce energy consumption and CO<sub>2</sub> emissions were lacking, which in turn also took into account the building and economic feasibility. In this way, the development of both tools can be interpreted as suggestions for new ways of coordinating data and structuring practices.

Von Hippel & von Krogh (7) emphasise open source/free revealing of product and process design as a key feature of open innovation. The special feature of both tools is that the tools are freely available for all and both tools can in this respect be regarded as a metaphor for open source in construction. Von Hippel & von Krogh (7) introduce three models of innovation incentives: 1) The Private Investment Model, where the assumption is that *'Innovators will gain higher profits than free riders only if innovations are not freely revealed as public goods'* ((7) p 303), 2) the Collective Action Model, where the assumption is that *'Innovators and free riders profit equally from innovations contributed as public goods'* ((7) p 303), and 3) the Private-collective Model, where the assumption is that *'Innovators gain higher profits than free riders from freely-revealed innovations because some sources of profit remain private'* ((7) p 303). They argue that the Private-collective model exists as an alternative to the other two models, and

is possible because the innovators despite free revealing of innovations get private benefits such as learning, enjoyment and affiliation to teams, communities etc. Innovation incentives for both tools are considered to be a combination of options 2 and 3, as the tool is funded by an external fund, combined with self-financing. The essential point is that the tools have been developed by innovators and then been made freely available to all. At the same time the tools have been available for free for several years, making it possible to examine both the development and use of tools. The information content of the cases strengthens the study's potential to produce knowledge on innovation and anchoring strategies for digital tools that are subsequently provided free of charge. Conversely, this at the same time limits the study from producing knowledge about model 1. The concepts of the tools are described in Table 1.

Tool	Web-based tool 1 (2006)	Web-based tool 2 (2008)
Initiator	Consultants e.g.	3 major property managers
Innovator	Consultant and architect	Consultant and architect
Free riders	Consultants, property managers	Major property managers
Aim	The tool is designed for apartment blocks. The tool build up a 3D model of the apartment block based on entered data. The tool link different retrofitting solutions, calculations of the economic profitability of capital investment and subsequent operational savings. It is a dynamic system.	The tool is designed for office buildings. The digital tool pulls data from the energy certification database on the specified building and link technical knowledge of energy-optimised solutions with calculations of the economic profitability of capital investment and subsequent operational savings. It is a dynamic system and shows the correlated energy label.

*Table 1: The concepts of the tools*

The two cases have been studied by applying documentary analysis of project descriptions and project documentations and interviews with innovators and users of the tools. The interviews were conducted with key participants chosen as they were highly involved in the developing process and subsequent use. The interviews were conducted as semi-structured interviews and the themes were sent to the interviewees before the interview. All the interviews were recorded and transcribed, and researchers also took extensive notes to inform their interpretation and analysis.

### **Analysis**

Both tools were developed in a period when it was perceived as difficult to prioritise the energy retrofitting initiatives to be implemented for both consultants and clients. This manifests itself in that tool 1 is initiated by consultants, while tool 2 is initiated by three major property managers. Tools 1 and 2 are both developed by consultants.

Tool 1: The tool was initiated by a consulting company that worked with urban renewal projects and as part of their service designed applications for funding for projects to the municipality. It was another consulting company with experience in energy retrofitting,

which developed the tool. Experience with the use of the tool at the company, which had initiated the tool, was that they had used it in the beginning, but had stopped using it. The tool was used to generate graphical illustrations of the energy impact of the selected energy retrofitting initiatives that were put together with the applications. In the period, when they used the tool, the applications were received positively. The interviewees' experience with the use of the tool was that he had to change underlying figures since their empirical data for example costs were different. His assessment was that they did not get different results out in terms of energy retrofitting initiatives than they would have done without the tool, but the advantage was that they could generate graphical illustrations. The reason why they did not use the tool more was that the municipality gradually became more conscious of what they wanted and used the energy certificate as a basis for their assessment of urban renewal projects. In this way, the energy certificate had taken over the function of tool 1 to document the energy impact of the initiatives. It is not expected that the tool will be updated or developed further.

Tool 2: The tool was initiated by three property managers and the tool was developed by a consultant company and an architectural company. A large municipal property manager (not one of the initiators) was selected as user of tool 2. The interviewee (user) is employed in an analysis section and worked to prioritise buildings where there was potential for savings in energy consumption through energy retrofitting. The large property manager wants to establish a closer link between the analysis section, the construction section and the operating mode to enhance knowledge-sharing between the different functions as a way to strengthen the organisation's competence to handle the increased political demands of the existing buildings energy performance. There were ongoing organisational changes and an intensified focus on real-estate data, databases and data management, where the long-term desire was that operating data should feed into the prioritisation process. The property manager has gone through an energy certification process of their buildings in line with legislation. However their experience was that they could not gather all the background data from the energy certification process in a common database as energy consultants had used different systems for data entry. Furthermore the data contained errors. The employee is a qualified engineer and has experience of using the tool, but he does not apply the tool himself anymore. He does not believe that there are others who make direct use of the tool, but it is still used through consultancy work. The employee had used the tool before, since it provided an easy access to the energy certificate database and the data were presented in an appropriate manner. When writing a property, the tool downloads data from the database, which at that time was not directly available in other ways. At the same time, the tool made it possible to work dynamically with the background data of the energy certificate, which made it possible to examine what was needed to achieve a better rating. It was also possible to deselect proposals mentioned in the energy certificate report, but that was not realistic in relation to the particular properties. The problem with the tool was that if you do not use it often, you forget how to use it and there were some inconveniences. The employee's experience was that when there was a proposal which went on to realisation by the





construction section, the developed material was not used. The consultants wanted to carry out assessments on the basis of the physical buildings.

Tool 2 has also been used by both the consultant and the architect who developed the tool. Both have developed the use of the tool further by using it as a tool for portfolio analysis for large customers. In both cases it has been possible because both the consultant and the architect have been able to change the underlying parameters as a way to customise the tool for different building types and forms of use. One of the analyses was performed for the property manager where the use of the tool is investigated. This analysis is used for selection of buildings, but still the produced material are not used in the further process, e.g. in the construction section. The portfolio analysis was perceived relevant, because it was a way to provide data on.

### **Discussion and conclusion**

The development of both digital tools is context-dependent. Both tools are developed in line with consultants' framework of understanding and tightly coupled to the optimisation of existing practices or development of new consulting services. For both tools, the experience was that it required specific skills, which largely reflected the innovators' skills in using the tools. It was also remarkable that it was the innovators of tool 2 themselves that were able to develop the use of the tool further. This is aligned with von Hippel and von Kroghs finding that innovators gain higher profits than free riders from freely-revealed innovations because some sources of profit remain private (7). The survival and stabilisation of the tools is dependent on the development of energy retrofitting in the network around the tool. For tool 2, it appeared that the coupling to the energy certificate database made the tool relevant for users despite other difficulties with both the tool and the energy certificates. Motivation for the property manager to use the tool was that it provided access to the data behind the energy rating. For tool 1, the opposite situation occurred as the energy certification system helped to clarify the Public Authorities and therefore the usefulness of the tool 1 was reduced.

It seems that the emergence of digital tools conceptualise the understandings of problems and solutions from the position of a project perspective if it is project-based companies as architects and advisors that have developed the digital tools. This remains the project perspective on the prioritization process and further stabilisation can keep the separation between planning, energy retrofittings activities and operation at major property managers through stabilising of practices and data structures that maintain this separation. Large property managers need to establish a data infrastructure between operations and planning, where operating data feeds into both the optimisation of operation, prioritisation and initiation of retrofitting activities. It should be explored further whether this type of digital tools work against major property managers building their own data infrastructure and reduces the possibility of working strategically with energy performance in the long term.



## References

- 1) Harty, C (2006) Innovation in construction: a sociology of technology approach, *Building Research and Information*
- 2) Gina Neff, Brittany Fiore-Sifvast & Carrie Sturts Dossick (2010) A case study of the failure of digital communicatin to cross knowledge boundaries in virtual construction , *Information, communication and society*.
- 3) Jaradat, S. Whyte, J. And Luck, R. (2014) Professionalism in digitally mediated project work *Building Research and Information*
- 4) Bijker, W.E. (1992). The Social Construction of Flourescent Lighting, or How an Artifact was Invented in Its Diffusion Stage, in Bijker, W.E. & Law, J. (ed.) *Shaping Technology/Building Society*, The MIT Press, England
- 5) Bijker, W.E. (1995). Of Bicycles, Bakelits, and Bulbs, Toward a Theory of Sociotechnical Change, The MIT Press, Cambridge, Massachusetts, London, England
- 6) Flyvbjerg, B. (1991). *Rationalitet og magt. Bind 1. Det konkrete videnskab.* København: Akademisk Forlag
- 7) von Hippel, E. & von Krogh, Georg (2006). Free revealing and the private-collective model for innovation incentives. *R&D Management*. 36(3), 295-306.



## Carbon neutral living in a modernised settlement house

Krüger, Christian<sup>1</sup>

Wilken, Thomas<sup>2</sup>

<sup>1</sup> VELUX Deutschland GmbH, Hamburg, Germany

<sup>2</sup> Technical University of Braunschweig, Braunschweig, Germany

**Abstract:** The „LichtAktiv Haus“ is a typical 1950s settlement house, transformed into a zero energy home for the IBA Hamburg international building exhibition. The „LichtAktiv Haus“ demonstrates that it is possible even for existing buildings to be exceptionally energy efficient. Moreover, the life cycle assessment of the house showed that the „LichtAktiv Haus“ has less impact on the environment than a comparable building certified by the DGNB (German Sustainable Building Council). Since December 2011, a family of four has been putting the theoretical planning and calculations to the test in practice. The interdisciplinary research, carried out in this way for the first time on a zero energy home, should help to answer the fundamental question of what is really important in terms of the future quality of living, and how future demands on the energy efficiency of a building can be met while maximising the consumer's experience.

**Keywords:** *Livability, energy efficiency, life cycle assessment, living experiment, scientific monitoring*

### Searching for construction and lifestyle solutions of the future

Sustainable, climate-neutral construction and lifestyle are the greatest challenges currently facing the construction and real estate sectors. However, the focal point in the realisation of any energy efficient building product should always be people and their emotional need for a home in which they feel completely at ease. With its Model Home 2020 project, VELUX is looking for new ways to combine optimum liveability with optimum energy design. In six projects across Europe, the company, together with experts, has developed new ways of living and working which include pleasant indoor climates, use of natural light and optimum energy efficiency (figure 1).



Figure 1: Locations of the six houses in the VELUX Model Home 2020 experiment

All six of the buildings created for the VELUX Model Home 2020 experiment in Denmark, Germany, Austria, France and England were developed in collaboration with local architects, engineers and higher education institutions in order to reflect the typical housing and lifestyle of the respective country in the underlying architectural design of the building. The „LichtAktiv Haus“ – the modernisation of a 1950s settlement house in the Wilhelmsburg district of Hamburg to a zero energy home – is Germany's contribution to the experiment. It is also a project of the IBA Hamburg international building exhibition which is a city development scheme facing up to the demands of future standards of living. VELUX contributes to the climate protection project "Renewable Wilhelmsburg" through its partnership with IBA Hamburg.

### **From design to implementation: creating the „Lichtaktiv Haus“**

The starting point was an unimproved 1950s semi-detached house in the Wilhelmsburg district of Hamburg. With a ground area of around 64 m<sup>2</sup> plus a small extension originally used as a shed, the building no longer met current requirements in terms of room size and height. In the run-up to the planning process, an ideas competition was held which saw students from Darmstadt University of Technology putting forward creative suggestions for modernising the old settlement house. As well as energy design and measures to improve liveability, an expert panel also assessed the architectural creativity of the designs. The winner of the competition was Katharina Fey with her design "home grown" (figure 2, 3).



Figure 2: The winning design "home grown"

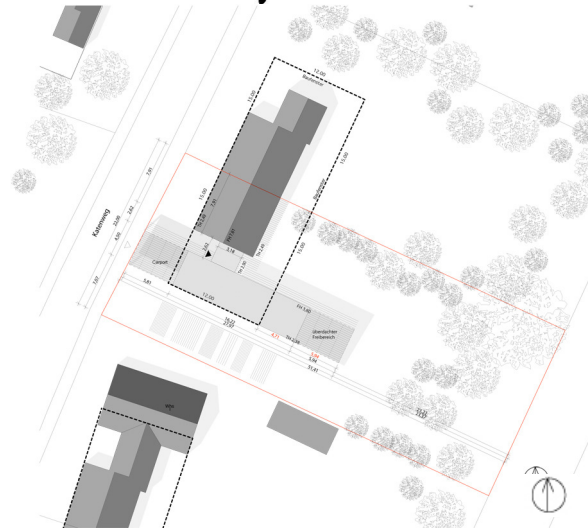


Figure 3: Site plan

### Focus on living comfort and energy efficiency

In order to provide additional living space and floor area and create more freedom for individual needs, the extension was replaced by a new one and the original building was extensively modernised. This meant that the closed-off, small room structure was opened up to create generous sleeping, living and traffic areas (figure 4, 5). As part of the restructuring and modernisation work, it was also possible to create a floorplan with an open aspect.



Figure 4: The Situation 2009



Figure 5: LichtAktiv Haus after climate renovation

Sophisticated use of daylighting provides the building with plenty of light and fresh air, and ensures a sense of wellbeing and comfort. The rooms are flooded with natural light so that even on cloudy days, there is hardly any need for artificial lighting. Moreover, the skylights play a key role in providing ventilation for the building. The window openings in the air-tight structure of the building are controlled automatically dependant on temperature, CO<sub>2</sub> levels and humidity, to ensure a healthy indoor climate thanks to this natural ventilation.

The new extension is also at the heart of the innovative energy design: together with an air-to-water heat pump, the photovoltaic modules and solar thermal collectors installed on the roof of the extension provide all the energy required for heating, domestic hot water and electricity in the „LichtAktiv Haus“. The heat for nearly all rooms of the building is distributed by a low





temperature underfloor heating system with a very low installation height. Warm water is generated using the continuous flow principle. To reduce water consumption, the toilets, garden irrigation and washing machine use greywater which is stored in a cistern in the front garden.

### **Life cycle assessment proves practical relevance**

A life cycle assessment carried out by Darmstadt University of Technology indicated that the environmental impact is significantly lower than that of a comparable DGNB-certified building and would be partly, or perhaps even entirely, compensated over the course of the building's life. The compensation is realized by the intelligent use of a range of renewable energies like solarthermal collectors, PV-cells and ambient heat. The assessment takes into account the whole life cycle – from manufacture, operation and upkeep through to disposal of the building structure. The use of the existing primary structure of the building, which no longer needed to be built and therefore contributed no environmental impact to the assessment, in addition to the logical design of the new construction with a wooden frame were crucial to the environmental impact of the building structure being somewhat significantly below that of the DGNB-certified comparator. Moreover, as existing houses in need of renovation can be considered an almost inexhaustible resource, the potential relevance of the life cycle assessment of the „LichtAktiv Haus“ for specifiers, owners or purchasers becomes apparent.

### **Living experiment combines quantitative and qualitative research methods**

The key part of the experiment began in December 2011, when Christian and Irina Oldendorf and their two sons Lasse and Finn moved into the house. Their task as a test family is to put the VELUX „LichtAktiv Haus“ to the test until the middle of 2014. This living experiment is accompanied by extensive scientific monitoring whose underlying concept combines both quantitative and qualitative methods of investigation for the first time. During the test period, researchers from the Institute of Building Services and Energy Design at Braunschweig University of Technology are measuring and documenting energy produced and consumed in the house, as well as recording quantitative data about the indoor climate such as temperature, relative humidity and CO<sub>2</sub> levels in the air. Alongside these quantitative measurements, an interdisciplinary team of architects and sociologists from Darmstadt University of Technology and Humboldt University of Berlin continually record the experiences of the test family through interviews and on-line surveys to make a direct correlation between the personal comfort and wellbeing and the quantitative data.

### **The low heat requirement validates the building design**

The test family's happiness with the house and the good performance of both the building and the technology seem essentially to validate the theoretical calculations and design of the VELUX „LichtAktiv Haus“. Both the solar thermal yields and the harvest from the photovoltaic system of 7.690 kWh/a are above the calculated values of 7.060 kWh/a (figure 6).

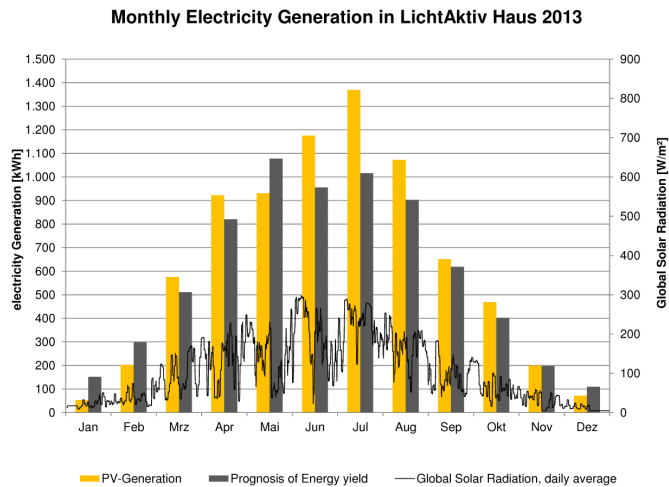


Figure 6: The yield from the PV system exceeds the calculated values

At the same time, the requirement for additional heating in the building is lower than initially calculated. One reason for this is the high quality of the building envelope. The needs-oriented and controlled natural ventilation ensures best possible air-quality and at the same time avoids inadequate ventilation heat losses. In addition, solar heat gains through the skylights have a considerably greater effect than in less well insulated buildings, due to the minor overall need for heating.

This outcome leads to the conclusion that heat loss due to ventilation with adequate natural ventilation does not lead to higher energy consumption without heat recovery. Moreover, the chimney effect causes pleasant indoor temperatures, thanks to the storage mass of the building and the nighttime ventilation.

### **The system's high consumption of energy requires optimisation**

Although the family's energy consumption, at 18 kWh per square metre per year, is comparable with other reference buildings, the energy used by the heating system is roughly 55 % above the calculated values. This excess consumption by the heat pump of approx. 2,500 kWh/a matches the deficit, leading to an even or positive balance, and as a result the target of "zero energy home" was not achieved in 2013 (figure 7).

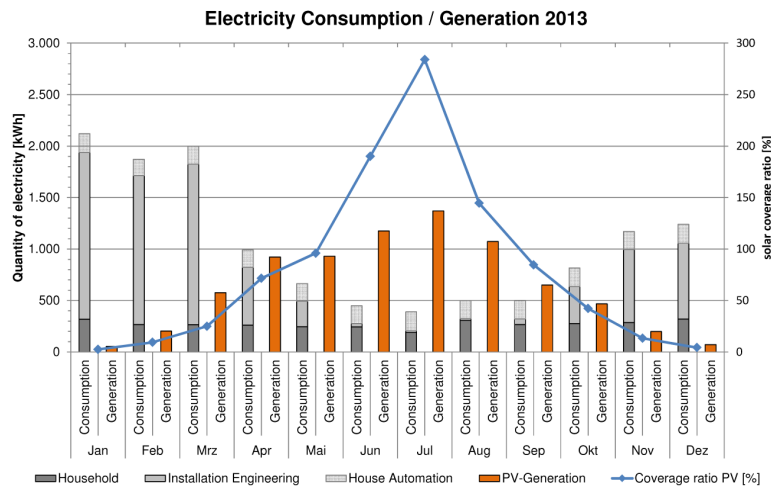


Figure 7: The energy consumption of the „LichtAktiv Haus“ cannot be completely covered by the PV system

The cause of this lies mainly in the complexity of the entire system and the presetting of valves, pumps and controls. A standardisation calculation of consumption carried out by the scientists at Braunschweig University of Technology, confirms that the control of the system equipment used for heat generation requires optimisation. Furthermore, the experiment has shown that the solar thermal energy system is too largely dimensioned for a family of four. Therefore, the yields which cannot be used or stored must be diverted to the heat pump via the external unit in summer. This “re-cooling” leads to increased power consumption of the system equipment in the summer months. To avoid this power consumption, Velux and the participating scientists have decided to add a geothermal system to the experiment. In the summer months, the surplus solar energy produced is stored in the ground soil to provide a higher temperature level in winter. This increases the solar coverage and reduces the energy consumption in winter.

### Residential well-being as a multi-dimensional construct

Parallel to the physical measurements, sociologists from the Humboldt University in Berlin are investigating perceived experiences of the occupants of the LichtAktiv Haus. The objective is to gain an insight into how sustainable living impacts on the well-being of occupants. The basic idea for the well-being study of living is a three-dimensional attitude model, which distinguishes between three categories of reactions to attitudes – affective, cognitive and conative – which can be expressed verbally and non-verbally.

The brightness, functionality or social environment of the LichtAktiv Haus, for instance, trigger certain feelings in the occupants (affect), give rise to certain opinions (cognition) and influence behaviour (conation). All these reactions can be measured. Since the attitudes, i.e. the residential well-being or the evaluation of it, change continuously due to experiences over time, the measurements must be repeated. It is, however, assumed that the number of new impressions decreases after a sufficient period of time, with the result that it is possible to make a relatively sound assessment of the liveability of a new home.

### The psycho-social monitoring of the Velux LichtAktiv Haus

The study design used in the living experiment in the LichtAktiv Haus consists of various instruments which make it possible to record the test family's attitudes towards their new home, as well as possible changes over time. This includes a detailed group discussion at the start of the experiment, as well as online questionnaires and structured interviews carried out at the end of each season with the family on site in the LichtAktiv Haus. The family records all their assessments of their living conditions in a digital logbook accessible to the monitoring team and reports on their experiences in the LichtAktiv Haus in a public blog. In addition, the scientists can compare the sentiments and behaviour of the occupants with the findings of the quantitative evaluation and optimise the technology if necessary.

### Impressive living comfort and indoor climate

The „LichtAktiv Haus“ offers its occupants a very high degree of living comfort. The division of space and the interior architecture of the „LichtAktiv Haus“ were perceived very positively by the test family, and the interviews that have been carried out show that, despite a few small criticisms, the family feels very happy in their new home. The comfortable temperature, optimal air quality and amazing amount of light in the rooms, in particular, were rated positively. The house's good indoor climate is another plus (figure 8). The values for relative humidity are between 45 and 55 %, making it very comfortable during the heating season. The CO<sub>2</sub> level in the air was likewise in line with expectations.

Perception of temperature in LichtAktiv Haus 2012

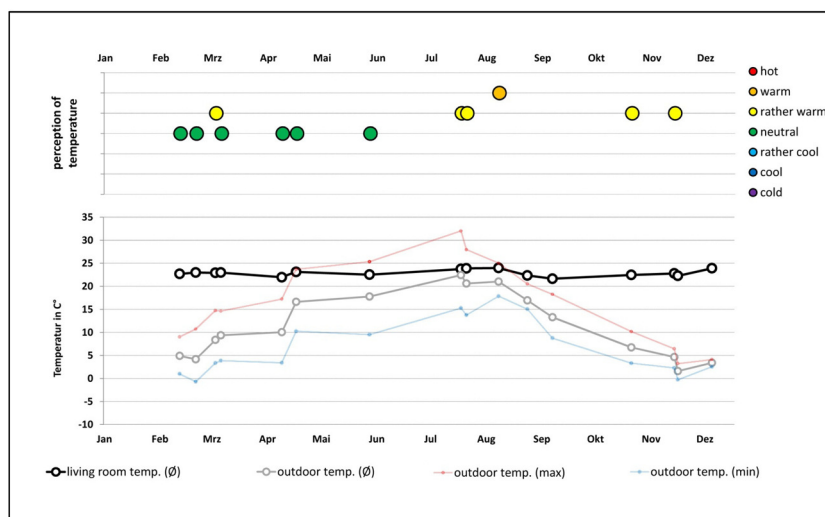


Figure 8: Temperature perception of the occupants

### Building technology promotes energy-saving behaviour

The functionality of the technology was rated as outstanding by the occupants, both as regards the automated operation and in terms of the customised control options. The noise caused by the automatic opening and closing of the windows was perceived as too loud, in particular at night. Moreover, after moving in, the family initially felt a lack of security due to the windows opening automatically while they were out. This feeling subsided with time. As it is possible to set the technology manually at any time, there was no point at which the test



family felt imposed by it; rather, they considered the automation to be a genuine asset. As a result of their new living environment, the occupants are demonstrating a greater awareness of the concept of saving energy, and have modified their energy consumption behaviour accordingly.

### **Conclusion**

With the „LichtAktiv Haus“ experiment, VELUX provides insight into construction and lifestyle solutions for the future. In the process by modernising an existing house, the company has taken on a task of relevance to the whole of society: around half of the 39 million residential properties in Germany are between 30 and 60 years old and in need of modernisation in terms of energy usage. This should not be at the expense of living standards or the health of the occupants. Future-oriented buildings should meet both needs: energy efficient and sparing use of natural resources, and at the same time healthy, attractive living spaces for enhancing wellbeing through plenty of natural light and fresh air.

The „LichtAktiv Haus“ exemplifies how optimum energy efficiency and optimum liveability can be brought together to create a future-oriented solution, even as part of an ambitious modernisation project. Rather than a passive house, where the design is based on an air-tight, very well insulated building envelope with "forced ventilation" and as few "loss areas", i.e. windows, as possible, the „LichtAktiv Haus“ follows the strategy of an active house, with automatic natural ventilation and an above-average proportion of window surface area. The result is optimum indoor air quality and generous amount of light in the rooms that significantly increase living comfort and are perceived positively by the occupants. At the same time, the house's measured heating requirement leads to the conclusion that heat loss due to ventilation with adequate natural ventilation does not lead to higher energy consumption without heat recovery.

The evaluation of the living experiment, carried out in this way for the first time, is situated at the interface between the four disciplines of architecture, engineering, sociology and psychology. The knowledge gained should help to answer the fundamental question of what is really important in terms of future quality of living, and how future demands on the energy efficiency of a building can be met while maximising the consumer's experience.



## Feasibility study of a hybrid ventilated classroom in hot-and-humid climate

### Speakers:

Kuo-Tsang Huang<sup>1</sup>; Ruey-Lung, Hwang<sup>2</sup>; Wen-Mei Shih<sup>3</sup>; Ming-Chin Ho<sup>4</sup>; Huey-Yan Liao<sup>5</sup>

<sup>1</sup> National Taiwan University, Taipei, Taiwan

<sup>2</sup> National United University, Miaoli, Taiwan

<sup>3</sup> National United University, Miaoli, Taiwan

<sup>4</sup> Architecture and Building Research Institute, Ministry of the Interior, New Taipei, Taiwan

<sup>5</sup> Architecture and Building Research Institute, Ministry of the Interior, New Taipei, Taiwan

**Abstract:** The research studied the feasibility of HV system applied to school classroom in hot-and-humid Taiwan. We adopted adaptive thermal comfort (ATC) models to simulate the operation of mechanical cooling in HV mode. As human's perception of thermal perception may differ from regions to cultural background, we firstly studied the applicability of ATC models proposed by ASHRAE standard 55 and EN15251 for subtropical Taiwan. Secondly, based on ATC model, the effectiveness of natural ventilation was investigated with local meteorological data for estimating HV energy saving potential. The conclusions are as follows: (1) ATC model suitable for Taiwan was identified. (2) The effectiveness of natural ventilation in hot-and-humid regions were evaluated. (3) Cooling energy saving potential of HV classrooms with mechanical cooling operated according to ATC model's comfort range were determined. This research provides quantitative understanding of the feasibility of HV classrooms in hot-and-humid climate in achieving sustainable purpose.

**Key words:** hybrid ventilation, thermal comfort, feasibility assessment, hot-and-humid region

### Introduction

Hybrid ventilation (HV), or also known as mixed-mode ventilation, is a building ventilation system that integrates natural and mechanical ventilation components to create a high efficiency and healthy ventilation system for a building. It is a two-mode system which is controlled to minimize the energy consumption while maintaining acceptable indoor air quality and thermal comfort and is considered as one of environmental friendly technology. Since it relies on natural ventilation (NV) to reduce the building cooling energy, the energy saving efficiency of HV system is closely related to regional outdoor climate. The objective of this research is to study the feasibility of HV system applied to school classroom in subtropical hot-and-humid Taiwan so as to provide reference for architectural designers doing passive design. The energy saving concept of HV can be elucidated as Fig. 1 [1].

The control algorithm of hybrid ventilation are described as follow and depicted as fig. 1.  $T_{fr}$  is the free-running indoor temperature under air tight condition and without any HVAC control. Temperature  $T_{cu}$  denotes to thermal comfort upper limit calculated according to adaptive thermal comfort model. It can be realized that in order to maintain indoor thermal comfort in summertime, there exists three control scenarios. (1) When  $T_{fr}$  is below  $T_{cu}$ , neither HVAC system nor NV is needed. (2) If  $T_{cu}$  is below  $T_{fr}$  and above the outdoor temperature ( $T_o$ ), fenestration is open to facilitate NV to achieve thermal comfort. (3) If both the  $T_{fr}$  and  $T_o$

are above  $T_{cu}$ , mechanical cooling is operated to maintain thermal comfort. That is, when a building is operated in HV mode, only scenario 3 is in need of energy and the cooling energy could be saved in comparison with traditional cooling system operation.

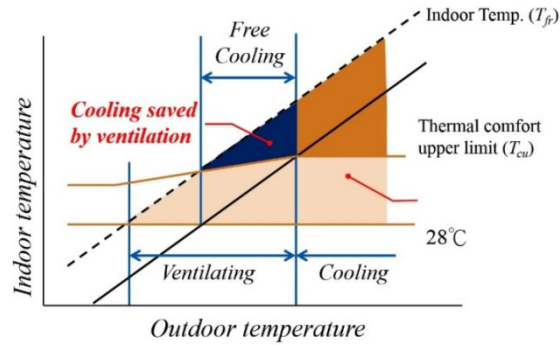


Fig. 1 Ranges for free-cooling and mechanical cooling when the indoor free-running temperature is higher than the outdoor temperature.

The research comprises two subjects, first to determine and identified applicable thermal comfort model by comparing their comfort ranges proposed in ASHRAE standard 55 [2] and EN15251 [3] thermal comfort models. Afterwards, the upper limit temperature ( $T_{cu}$ ) of the thermal comfort range from the identified model was used as HV control threshold to estimate the energy saving potential for three cities located in northern, central, and southern Taiwan.

### Thermal comfort models

Thermal comfort standards specify the range of conditions or comfort zones where 80% of occupants would feel the environment thermally acceptable. From various research in the recent decades, there is a strong consensus that adaptive comfort model is more suitable than heat balance based models when evaluating an environment that occupants have fully access to openable windows, thermostat settings, etc. to adjust their thermal feelings, which is the case in HV mode. There are two main stream standards in defining adaptive thermal comfort range are ASHRAE Standard 55 and European EN15251 standard. The predicted neutral temperature is a function of monthly outdoor temperature mean ( $T_m$ ) in ASHARE standard as eq.(1), whereas EN15251 standard adopts seven days' past outdoor temperature ( $T_{d-i}$ ) running mean ( $T_{rm}$ ) as eq.(2) and eq.(3). Previous studies showed that in Taiwanese climate context, there is an average of 1.5°C predicted neutral temperature difference annually between them. Therefore, there is a need to determine the thermal acceptability predicted by which standard is closer to Taiwan student's thermal responses. A local thermal perception analysis database established during 2003-2012 was used for comparing [4]. The database contains 6,932 valid samples in which 3,754 samples were derived from natural ventilated classroom subjects and the other 3,178 samples were from hybrid ventilated classroom. The database recorded each individual's thermal acceptability of subjective thermal perception votes as well as corresponding in-situ physical environmental measurements from a wide range of various thermal conditions of classrooms. Since, there is only air-conditioning used for cooling in classrooms, data and analysis for cool seasons in this study were omitted.

$$t_n = 0.31 \times T_m + 17.8 \quad (1)$$

$$t_n = 0.33 \times T_{rm} + 18.8 \quad (2)$$

$$T_{rm} = (T_{-1} + 0.8 \times T_{-2} + 0.6 \times T_{-3} + 0.5 \times T_{-4} + 0.4 \times T_{-5} + 0.3 \times T_{-6} + 0.2 \times T_{-7}) / 3.8 \quad (3)$$

### Methods for estimating natural ventilation (NV) effectiveness

Since HV building relies NV to remove internal heat gain, the capability of HV application depends on local meteorological conditions, especially on the effectiveness of NV. The effectiveness of NV is defined as the annual ratio of theoretical hours that indoor thermal comfort can be achieved simple by NV during building operation hours. A climate region with high NV effectiveness suggests that there is greater potential of energy saving by utilizing HV. The analysis of NV effectiveness is based on indoor-outdoor heat balance theory under the premises that indoor air quality as well as thermal comfort can be ensured. For a given building, NV is possible when indoor temperature ( $T_i$ ) is less than  $T_o$ , the total building heat gain (solar heat gain  $q_s$  + internal heat gain  $q_i$ ) deducted by the total building heat loss equals heat storage in a building, as eq.(4). Considering that when  $T_i$  variation is low, building thermal storage effect could be omitted. Therefore, eq.(4) could be rewrite in a steady state equation as eq.(5).

$$M \frac{dT_i}{dt} = q_s + q_i - UA_w(T_i - T_o) - \dot{m}C_p(T_i - T_o), \quad \forall T_i < T_o \quad (4)$$

$$T_i = T_o + \frac{q_s + q_i}{UA_w + \dot{m}C_p} = T_o + \frac{q_s + q_i}{UA_w + \rho C_p Q}, \quad \forall T_i < T_o \quad (5)$$

From the theory of adaptive thermal model, when operated in NV mode, occupants' expected  $T_i$  is higher than air-conditioned mode. Nevertheless, the  $T_i$  should also be maintained at within the range of thermal comfort zone predicted by the adaptive thermal model. Under the above premise, the applicability of NV is limited by  $T_o$ . The occupants will experience cold when  $T_o$  is too low. Therefore, based on pragmatic engineering application,  $T_o$  less than 12°C is considered not suitable for NV and are omitted in the analysis. Similarly, NV is ineffective when  $T_o$  is above indoor free running temperature ( $T_{fr}$ ). The maximum effective outdoor temperature ( $T_{omax}$ ) for NV application will close to indoor maximum thermal comfort temperature ( $T_{cu}$ ) predicted by adaptive thermal model. In this situation, the temperature difference between indoor and outdoor is small, heat conduction from building fabric can be neglected, therefore, the upper limit of  $T_o$  (i.e.  $T_{omax}$ ) for effective NV can be derived from eq.(5) and as eq.(6).

$$T_{omax} = T_{cu} - \frac{q_i}{\rho C_p Q} \quad (6)$$

where  $q_i$  denotes to internal heat gain (Wh/m<sup>2</sup>),  $Q$  is maximum air change flow rate (m<sup>3</sup>/hr);  $\rho$  is air density (g/m<sup>3</sup>);  $C_p$  is the specific heat of air (J/gK)

The typical school ceiling height design is 4.0 meter in Taiwan, considering maximum ventilation rate is 20 ACH, minimum temperature difference between  $T_{cu}$  and  $T_{omax}$  can be identified according to various degrees of internal heat gain ( $q_i$ ), as listed in Table 1. The hour when NV is either effective can hence be identified by observing the difference of  $T_o$  and  $T_{cu}$

of a given time, climate context, and internal heat density. Annual available NV hours can be estimated by accumulating the effective NV hours during classroom's operation hours. Consequently, the annual rate of NV effectiveness ( $\eta$ ) is identified by dividing annual available NV hours with annual building operation hours, which is 2,340 hours herein.

*Table 1 Maximum outdoor temperature required to maintain thermal comfort by NV under various internal heat gain*

$q_i(\text{Wh/m}^2)$	10	20	30	40	50	60
$T_{omax}$	$T_{cu}-0.70$	$T_{cu}-1.40$	$T_{cu}-2.09$	$T_{cu}-2.79$	$T_{cu}-3.49$	$T_{cu}-4.19$

### Methods for assessing energy saving potential of HV

A traditional way to estimate the amount of cooling energy consumption is by bin method in which it is evaluated for different temperature intervals and time periods [5]. This method calculates cooling degree-hours in each outdoor temperature bin base on accumulating every hour's temperature difference between the balanced and the outdoor temperature. While the indoor is cooled by air-conditioning system, this balanced temperature ( $T_B$ ) is supposed to keep in constant. In this study 28°C is used as balanced temperature as Taiwan's government requires schools that the cooling is available whenever the temperature is above it for energy conservation reason. The cooling energy consumption of traditional air-conditioning system is termed  $CDH_{ac}$ , and can be calculated by means of eq.(7). Contrarily, this is not the case while the building is in free-cooling mode, as this balanced temperature, according to adaptive thermal comfort model, would fluctuate in accordance with outdoor temperature. To estimate the theoretical cooling energy consumed in HV building, one have to firstly decide at which temperature free cooling is shift to mechanical cooling before the bin method is able to applied. In searching this balanced temperature variant, the adaptive thermal comfort model that suits for Taiwanese people was therefore adopted (herein the EN15251 model is considered more suitable for the application). The analogous cooling energy use in HV building can be estimated from eq.(8) and is termed  $CDH_{hv}$ . The energy saving potential of HV is defined as eq.(9).

$$CDH_{ac} = \sum_{i(day)} \sum_{j(hour)} [T_{o(i,j)} - T_B] \delta_{ac}, \quad \forall \delta_{ac} = \begin{cases} 1, & T_o > T_B \\ 0, & T_o \leq T_B \end{cases} \quad (7)$$

$$CDH_{hv} = \sum_{i(day)} \sum_{j(hour)} [T_{fr(i,j)} - T_{cu}] \delta_{hv}, \quad \forall \delta_{hv} = \begin{cases} 1, & T_{fr} > T_{cu} \quad \wedge \quad T_o > T_{cu} \\ 0, & T_{fr} \leq T_{cu} \end{cases} \quad (8)$$

$$\xi = \left( 1 - \frac{CDH_{hv}}{CDH_{ac}} \right) \times 100\% \quad (9)$$

### Suitability study of thermal comfort criteria for hot-and-humid region

As energy saving of HV building is achieved by turning off mechanical cooling system when indoor free running temperature is below the upper temperature limit suggested by the thermal comfort model, to speculate occupants' temperature endurance in a NV classroom, understanding which comfort standard model is close to the thermal responses for people living in hot-and-humid Taiwan is needed. The subjective thermal acceptability and objective physical environmental measurements recorded in database were used in comparison with the

predicted acceptability from ASHRAE standard 55 and EN15251 standard. From Fig. 2, we have learned that as the predicted neutral temperature is lower in ASHARE 55, both the measured and the voted frequencies that corresponds to the thermal comfort range is less than those in EN15251. It also reveals that most of the subjective responses are larger than the objective measurements regardless of thermal comfort categories, suggests that people are more tolerant than the model predicted.

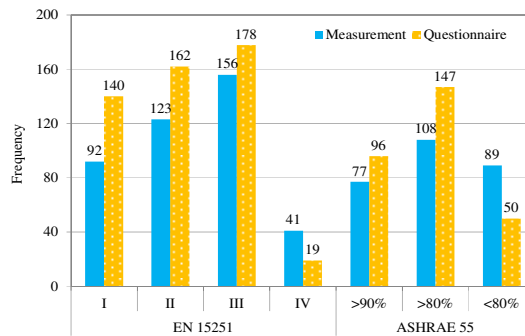


Fig. 2 Frequencies of objective votes and subjective measurements that meet the thermal comfort standards

To further understand the differences among the subjective responses and the models' prediction, inter-comparison on the percentages that corresponds to each thermal comfort categories of the two standards are plotted as in Fig. 3. The filled area in fig. 3 denotes to percentages that both the physical thermal condition and the occupants' responses are all thermally accepted. Considering the warm season, less than 10% difference from the filled area is observed in EN15251-category II and EN15251-category III, either for subjective responses or physical measurements, suggests that these two categories are closer to actual occupants' responses for the people in Taiwan. In contrast, the acceptable upper limit of indoor comfort temperature expected by Taiwan's people is higher than ASHRAE standard predicted. It indicates that thermal comfort range of category II and III proposed by EN15251 are more suitable for evaluating energy saving potential of HV application.

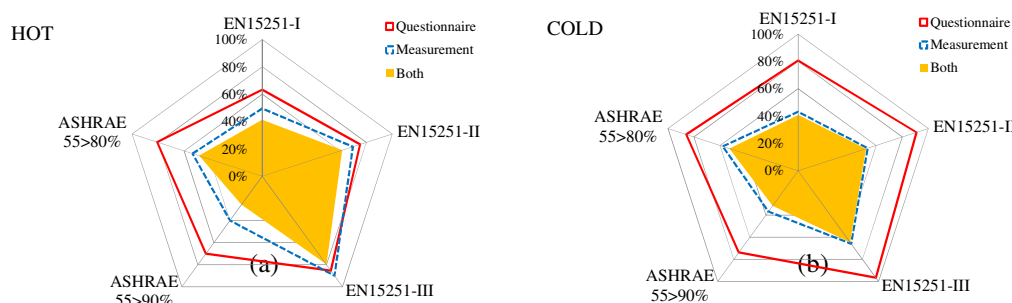


Fig.3 Percentages of subjective votes and objective measurements within thermal comfort range (a) warm season (b) cool season

### Energy saving potential of hybrid ventilation

The effectiveness of NV would decrease as internal heat gain increases. The definition of internal heat gain is the amount of heat generated by lighting, equipment, and occupant's body sensible heat discharge. Typical meteorological year (TMY) of Taichung city (located at



central Taiwan) constructed from 1998-2012 hourly climate database was used as climate surrogate for analyzing to ensure long-term climatic representative. Fig. 4 reveals how the estimated effectiveness of NV varies with internal heat gain density base on 80% ASHRAE standard 55 and the category III of EN15251 thermal comfort limit. The annual effective percentage of NV is 71% (for summer months it is 33%-74%) when the internal heat gain is  $10 \text{ W/m}^2$ , but it drops to 39% (for summer months it is 5%-25%) while the internal heat gain increases to  $60 \text{ W/m}^2$ , suggesting internal heat gain is an important factor that influence the utilization of HV.

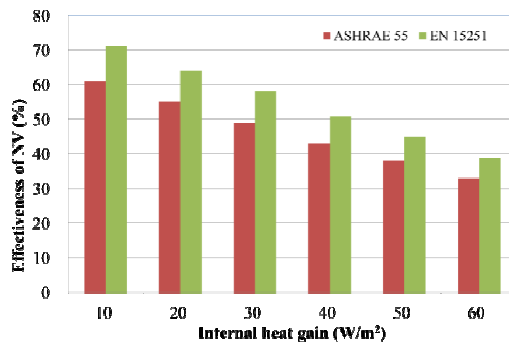


Fig. 4 Effectiveness of NV by ASHRAE standard 55 and EN15251

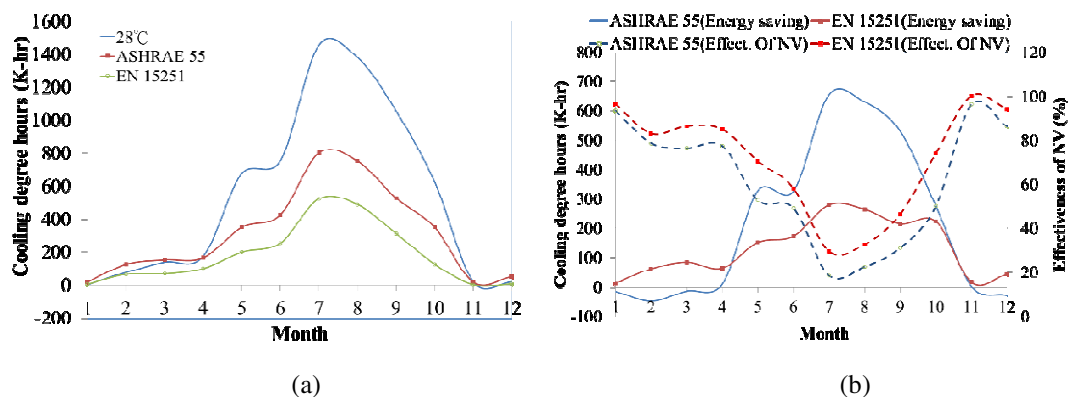


Fig. 5 (a) Comparison of estimated cooling degree hours of HV controlled base on ASHRAE 55 and EN15251 with traditional cooling control system (internal heat gain=10 W/m<sup>2</sup>) (b) Relationships between HV energy saving potential and the NV effectiveness.

The energy saving potential of HV is estimated by comparing  $CDH_{hv}$  against  $CDH_{ac}$  of traditional air-conditioning. The  $CDH_{hv}$  is calculated via eq.(8) base on thermal comfort models' upper temperature limit criteria, which are 80% in ASHRAE standard 55 and the category-II in EN15251. Supposed that the internal heat gain is  $10 \text{ W/m}^2$ , monthly cooling degree hour distribution is plotted as Fig.5(a). It reveals that main energy saving by HV occurred in summer from May to October when traditional cooling demand is high. By comparing monthly effectiveness of NV from Fig. 5(b), although there are high NV effectiveness during cool season (from October to next year April), the HV energy saving potential are limited for the reason of low cooling demand. Generally, it exhibits higher HV energy saving potential in hot seasons while assessed with EN15251, resulting higher annual energy saving than ASHRAE standard 55 does. It is worth to mention that, although the

energy saving potential decreases as internal heat gain increases, the actual saved energy or cooling degree hours are even larger due to there are higher  $CDH_{ac}$  for those with high internal heat gains. Take a classroom with internal heat gain for 10 and 60 W/m<sup>2</sup> in Taichung for example, the rate of energy saving potential decreases from 67% to 30% when assessed with EN15251, an additional amount of 906 CDH could be saved when the internal heat gain is 60 W/m<sup>2</sup>.

### Conclusion

The research drew to conclusions as follow. (1) The control algorithm of HV building can reference to adaptive thermal comfort model proposed by EN15251 standard. It is recommended that schools adopt category II criteria in EN15251 as operating strategies for HV in hot-and-humid Taiwan. (2) The NV effectiveness is generally higher in cool season than in warm season. For the months that need cooling, the effectiveness of NV is 18-53% when the internal heat gain is at 10 W/m<sup>2</sup>, but it will decrease with the increase in internal heat gain. (3) Compared with traditional cooling, the reduced annual cooling degree hours by HV operated classroom when internal heat gain is at 10 W/m<sup>2</sup>, there is 76.3% less on average assessed by EN15251, and is 39.7% less when the internal heat gain is at 60 W/m<sup>2</sup>.

### Acknowledgement

The authors would like to thank for the financial support from Taiwan's Architecture and Building Research Institute under project No. 102301070000G0011.

### Reference

- [1] Ghiaus, C. and Francis A. (2006). Potential for Free-Cooling by Ventilation. *Solar Energy*, 80(4): 402-413.
- [2] ASHRAE (2010). *ASHRAE Standard 55:2010-Thermal Environmental Conditions for Human Occupancy*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- [3] CEN (2007). *EN 15251:2007-Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*, Brussels: CEN.
- [4] Hwang, R.L., T.P. Lin, C.P. Chen, and N.J. Kuo (2009). Investigating the adaptive model of thermal comfort for a naturally ventilated school building in Taiwan, *International Journal of Biometeorology* 53:189-200.
- [5] ASHRAE (2001). *Fundamental handbooks*, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.



## **Modulation performances in the building envelope: strategy and project**

### **Speakers:**

Ausiello, G.<sup>1</sup>; Raimondo, M.<sup>2</sup>

<sup>1) 2)</sup> Department of Civil, Architectural and Environmental Engineering, University of Naples Federico II

**Abstract:** *This paper focuses on the analysis of a strategy aimed at improving the thermal performance of buildings thanks to the design of building envelope that could determine their natural thermal behavior, instead of fostering an excessive use of air conditioning systems. The true design innovation has the goal of conceiving envelope solutions capable of modulating the signals coming from the outside, so that the various structural elements that delimit the interior space could be able to re-emit them, strengthening or reducing them according to performance targets.*

*In the design phase the site analysis is fundamental: it has to include both environmental and climate factors in order to check the critical issues and those potentialities offered by the site that could be useful to control the indoor environmental conditions.*

*A methodological approach also requires the measurement of the performance to improve it, thanks to the use of iterative measurements and numerical models.*

**Key words:** *Natural performance building, building envelope design, thermal performance, minimum use of the air conditioning system*

### **1. Sensitive and reactive systems of the past**

"The best time to plant a tree was 20 years ago. The second best time is now." This proverb of Confucio emphasizes the delay with which we devote attention to the issues of energy efficiency and environmental sustainability that today dictate new "imperatives" that modify in different ways and at varying degrees the approach to new building design. These issues are not only very timely given the objectives that Europe poses urgently. But it is also important to consider all possible solutions to ensure the maximum comfort by minimizing the use of the air conditioning system. In recent years the success of new techniques of building construction has generated an increasing demand of welfare requirements to be satisfied by air conditioning systems that provide the energy needed to modify the air temperature according to external conditions.

The real goal should be to design today's climate spontaneous, recovering strategies of the past and offering them with the support of newer technologies and more efficient.

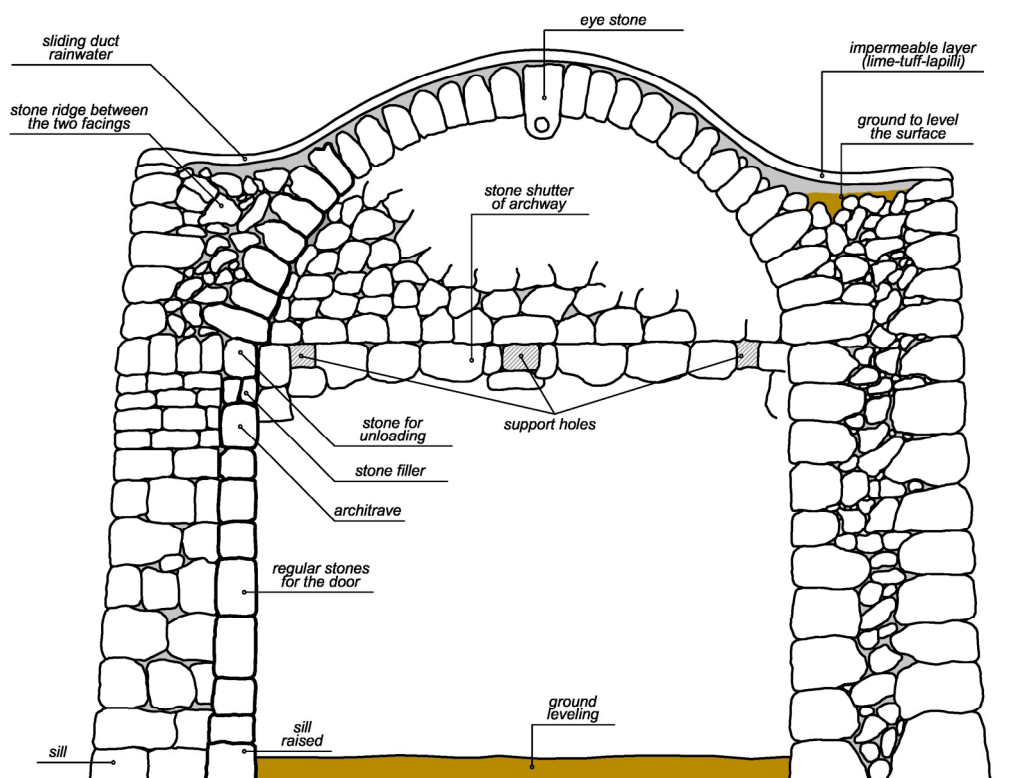
The relationship between design and climate, in wider terms "environment", which characterized largely past construction, has gradually disappeared during nineteenth century, especially with the advent of heating and air conditioning systems. Indeed, today, these are the main elements for government of internal conditions.

It is necessary to know the traditional architectural styles that came in succession over the centuries, in order to revive the built-nature alliance, and in order to take advantage of the climatization strategies based on the use of natural resources.

Infact, throughout history, when the shortage of energy resources and technological instruments limited control on the environment, construction methods have been developed. These methods have determined the selection of more efficient architectural solutions that are suited to local climates. It is easy to find examples in the traditional architecture (extreme examples of architecture are the Eskimo igloo, the Indian house of straw and mud).

In Italy Traditional architectures are “trullo” and “dammuso”. These are buildings and architectural systems with environmental materials, which developed many construction and architectural perceivable and responsive methods. These are consistent with the place and the environment in which they are. They aim to determine the spontaneous air conditioning in confined spaces.

Dammuso is a architecture of the island Pantelleria, characterized by strong winds throughout the year. Dammuso has simple shapes and is oriented exposing minor surface to the strong wind. The basic typological element is represented by one population cell which can join to other compact aggregations (Fig.1). The interiors have barrel-vaulted intrados and different curving extrados. The openings are the door and small windows called "stone eyes" which allow, although in small measure, the lighting and ventilation.



*Figure 1: A section of dammuso*

The high thickness of the wall ensures the delay of heat flows, which are mainly regulated by the cover. The extrados makes heating dissipation possible thanks to the radiation with the night sky. Barrel vaulted intrados contributes to the inner convective flows. In addition, the artifact implements direct thermal exchanges with the ground because it is directly placed on it.



This analysis shows that architecture developed millennial experiences. They highlight the potential for developing architectural and urban building systems which are perceivable and responsive of the place and of the environment. This guarantees a spontaneous air conditioning in confined spaces.

The inertial daily ability is added to sequential one that can counteract the prolonged heat waves. Current building systems are not characterized by similar inertial masses and the replication of these urban structures would not give the same favorable results to the spontaneous air conditioning.

So the redefinition of a proper relationship between buildings and the environment should recover this constructive logic and support a new culture based on the science and technology domain. As a consequence, it gives the new standards and building systems in relation to the environment and the climate.

In the last years, the air-conditioning systems advent has reduced the attention on the volumes and envelope design, which has lost its primary function as a mediator between internal and external climate, leading to independence from climate. As a consequence, it is strategic to work for ensuring the project summarizes its original function. It has to constitute the key moment to establish the architectural and technical conditions necessary to comfortable internal conditions, taking advantage of technological and disciplinary advances currently available.

New building systems should have very low energy requirements, sensitive to a specific climate, and they should manage the indoor climate for long periods with almost automatic reactions to external environmental stimuli.

These reactivities are concentrated, but not exclusively, on building behavior and in its architectural and technological connotations.

## 2. Adaptivity

The real innovation is to rule the spontaneous building behavior and its responsiveness to the environment for controlling the internal conditions, during the seasons, with few systems.

This is possible with a proper and an *in-depth analysis of the thermal situation* (more generally of the environment), and with the design of the building volume and the *choice of building envelope solutions* that can modulate external signals. Finally, after contextual conditions are examined, it is possible to use analytical modeling for the prediction of spontaneous building behavior in free floating (free floating is an environmental condition defined by the behavior of the building, without the systems participation).

The objective is to reduce the use of traditional heating and air conditioning systems, the use of non-renewable energy and CO<sub>2</sub> emissions. Nevertheless, it is necessary that the internal conditions are comfortable.

Michael Humphrey and Fergus Nicol in 1992 developed an approach called "adaptive", which provides that man is able, within certain limits, to respond to environmental changes. This is possible with physiological and behavioral reactivity, with interventions and adjustments to the building system, opening or closing a window, lowering a curtain or wearing a sweater or temporally moving an activity.



The man's reaction takes place through physiological adaptabilities (thermo-hygric regulation of body), which change as a function of environmental conditions, and through conscious or unconscious adaptation, generated by psychological conditions. In fact, the individual has expectations because he uses to live in a given environment. This expectation, in air-conditioned spaces, leads to accept non-natural situations where the user cannot influence. In this manner, the use of air conditioning becomes raised with significant influence on the increase of energy consumption. The individual influence, in the first activity, is limited and conditioned by acclimatization but it becomes important in the second adaptivity form.

When it is possible to take advantage of the individual adaptivity, performance targets are less stringent than those set forth above, because remaining acceptable (without reducing the current expectations of quality), are based on the natural imperfect constancy of environmental conditions that is found precisely in the natural world.

In 2000 ASHRAE got started on a research for the revision of the ASHRAE 55-1992. The purpose was to develop a new standard that was specifically applicable to naturally ventilated spaces: the results (Standard 55 Thermal Environmental Conditions for Human occupancy, 2010) have shown that in these environments, a variable percentage between 80% and 90% of subjects tolerates less stringent temperatures and temperature ranges (Fig.2 and Fig.3). The new standard is perfectly applicable to this study.

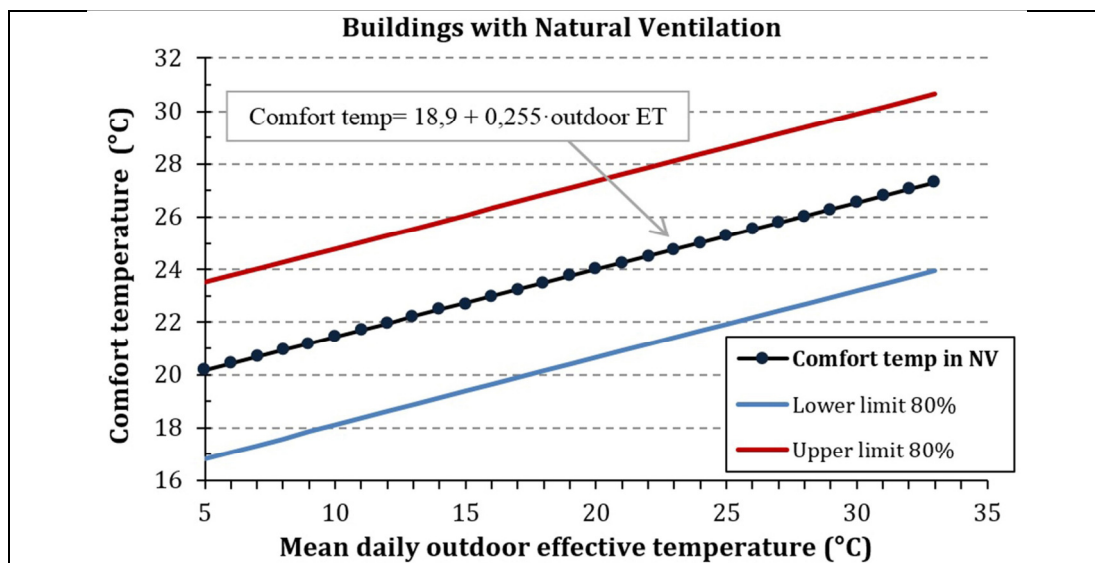


Figure 2: Optimal comfort zone for 80% of subjects in naturally ventilated and then with adaptive behavior to vary the effective temperature outdoor (BRAGER, G.S., DE DER, R.).

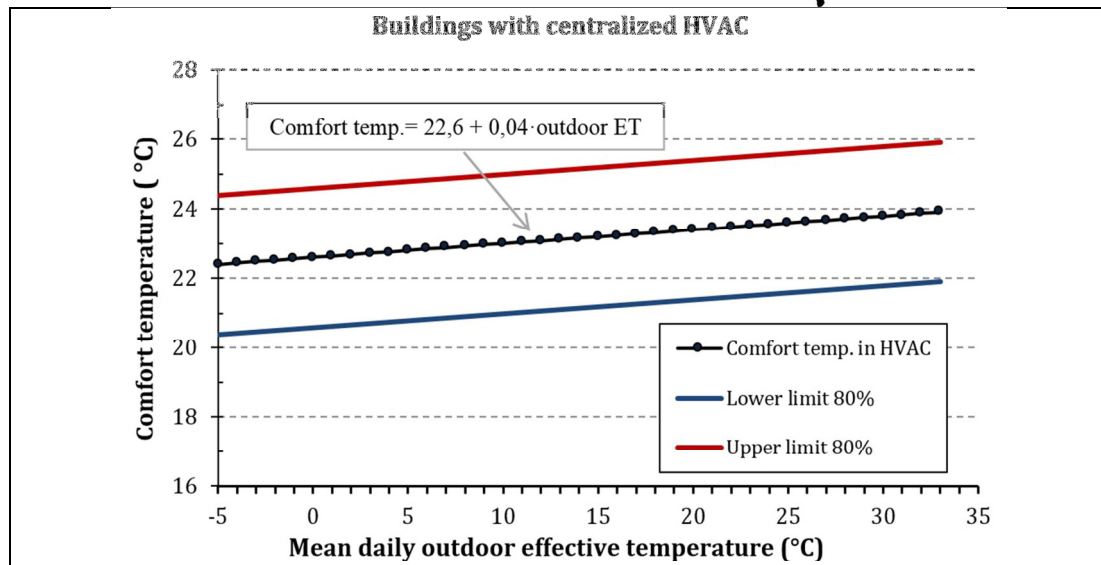


Figure 3: Optimal comfort zone for 80% of the subjects in a conditioned environment to vary the effective temperature outdoor (BRAGER, G.S., DE DER, R.).

### 3. Microclimatic context analysis in the design approach

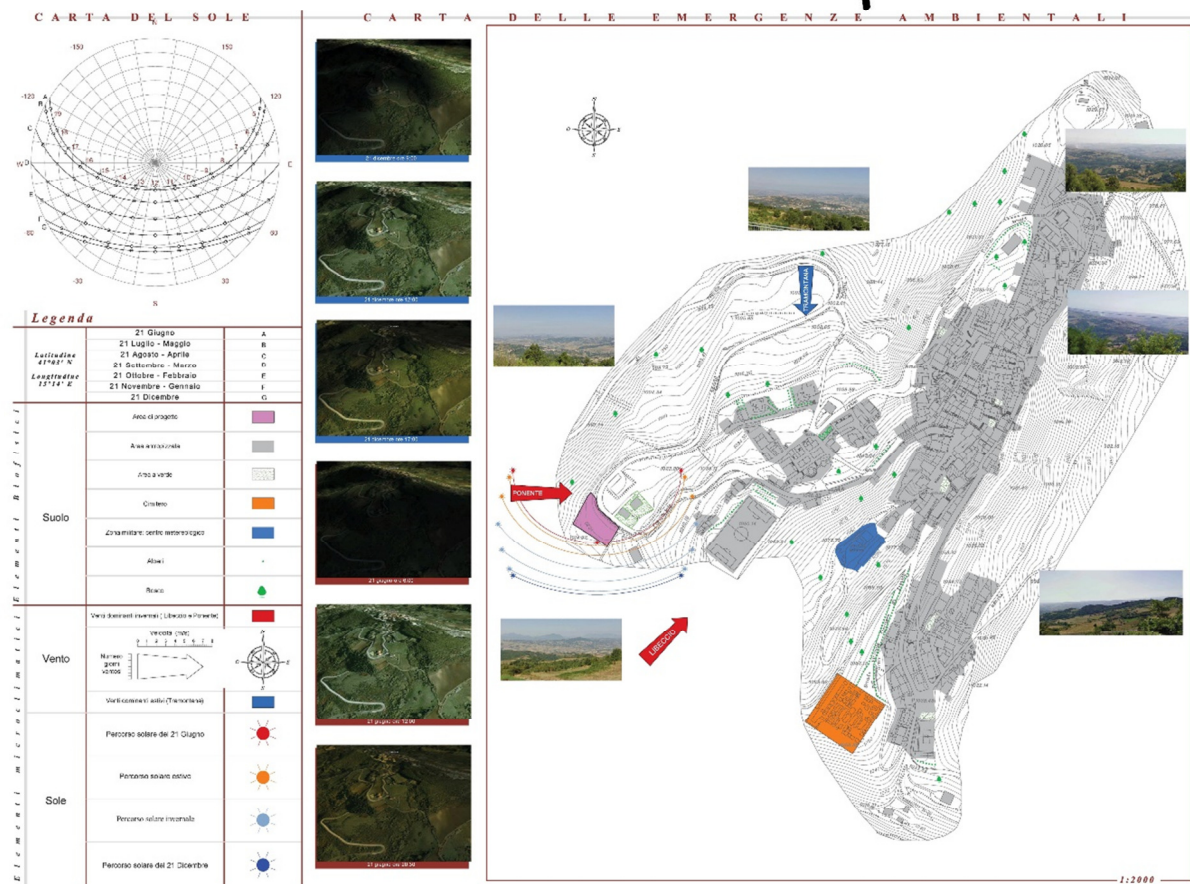
Italian climate consists of multiple climatic zones: alpine areas, Apennine areas, areas of pre-Alps, lakes, level grounds, marine areas. They have different latitude, sun exposure, clouds, wind, presence of breezes, vegetation, orography, presence of aquifer, urbanization etc... There are sites where summer conditions prevail, other where winter climates prevail and there are sites with very hot summer and cold winter.

The purpose of activating, during seasons, the environmental conditions of well-being thanks to the use of non-renewable sources, highlights the need to know and use the full potential of the site facing the most critical aspects the climatic context.

It is necessary to know and use local potentiality for using non-renewable sources. For each site, it is necessary to analyze which are the critical issues (negative force) and the potentialities (positive force) for controlling the internal environmental conditions.

It is necessary to deepen the knowledge of the context data during seasons. It is crucial for evaluating the performance of the internal environmental conditions, compared to the variability of external environmental stimuli.

The collected data can be synthesized on environmental emergencies map (Fig.4) in which there was the solar path, the prevailing winds, the green areas and farmland, views, the infrastructure and the buildings close to analyzed area. This allows to identify and summarize potential issues related to the site and then to make more accurate design decisions.



#### 4. Building envelope design

In relation to specific microclimatic conditions, the design purpose is to conceive envelope solutions for modulating external signals. As a consequence, various technical elements of envelope emit them again, transforming, strengthening and reducing them. The purpose is to introduce new signals in the environment for obtaining the performance targets.

Therefore, it is necessary to make a design centered on government of building dispersing surfaces, rather than aimed to the control of air temperature.

The envelope becomes a signal generator. The control of envelope depends on the perceived environmental quality.

It is evident the design potential in new envelope development respecting environmental quality and sustainability. The lack of potentiality comprehension, and the reproduction of stereotypes often leads to use systems.

In general we can distinguish two types of surfaces. Their modulation define the achievement of a given operating temperature:

- opaque elements;
- transparent elements.

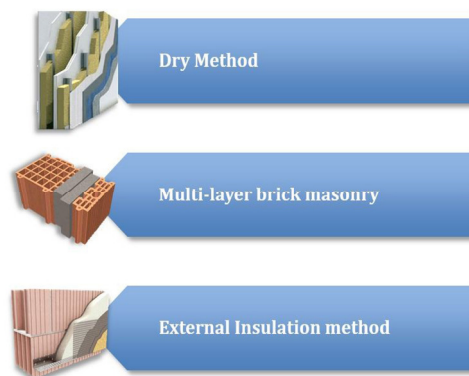
The most popular strategy for reducing energy winter consumption is to increase the closing thermal resistance, insulating the opaque parts or using high thermal inertia. As a result, the transparent closures have to govern the thermal flows.

In summer conditions, in analogy to winter conditions, it is still necessary operate on modulation of opaque or transparent closures for achieving optimal environmental conditions. The difference between winter and summer regime is that transparent winter open closure (including screening systems) handles the heat flows through the solar factor, but also the heat flux for mass transfer in natural ventilation.

In fact, glass transparency, for the energy transfer, is an advantage during the winter season and a disadvantage in the summer. So the focus of the technological development and new materials is particularly directed toward the improvement of glass performance. This should be different in relation to climate change and different glass orientation.

Obviously, glass surfaces with high thermal insulation are necessary where the winter is colder. Solar control glass surfaces with possible dazzle protection are suitable where climate is warm. For temperate climates, depending on the season or time, both requirements could be satisfied with appropriate innovative dynamics solutions. Generally, for South exposure glass should maximize winter solar gain, while for other orientation, glasses should improve thermal insulation.

As a result, after microclimate analysis and after an architectural solution design that is a good compromise between the need for maximum uptake of solar radiation in winter and maximum sun shielding in the summer season, it is possible to choose an envelope solution. Nowadays, it is possible to find on the market the different types of construction in the following three main categories (Fig5):



*Figure 5: Different types of construction*

To make a performance evaluation it is necessary to analyze the thermophysical parameters in technical files for the possible opaque closures solutions.

The figure 6 describes the stratigraphy of the vertical closure solution, the graphical representation of the detail, the dynamic parameters and the interior and exterior surface temperature during the 23th July.



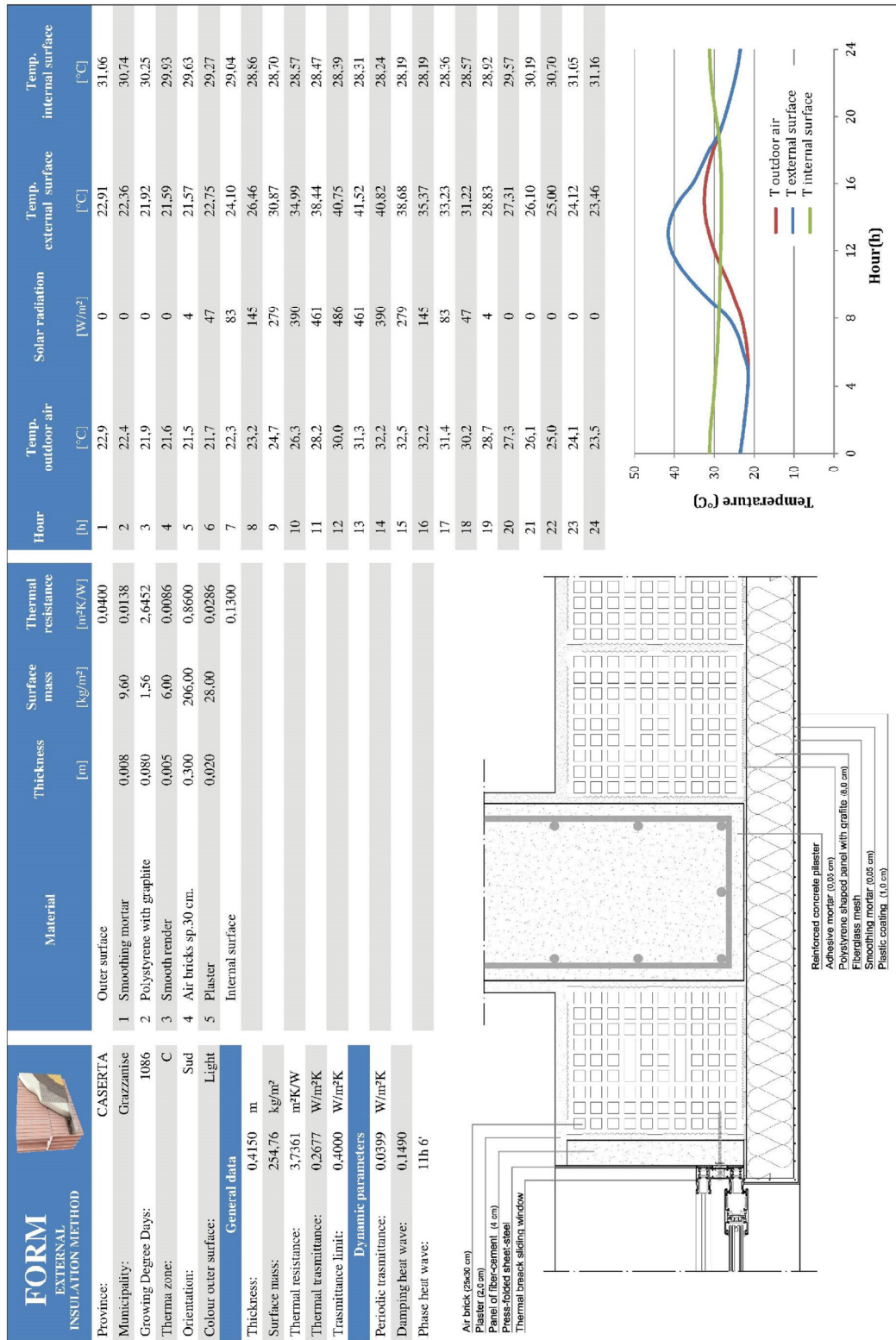


Figure 6: Evaluation form

This is followed by behavior analysis in steady state during the winter and in semi-steady state during the summer: in this manner we calculate the output and input conductive heat by varying the vertical solution of dry method, multi-layer brick masonry and external insulation



method. It is obvious that, during the summer, the calculation is made by differentiating the element opaque vertical orientations in relation to North, South, West and East.

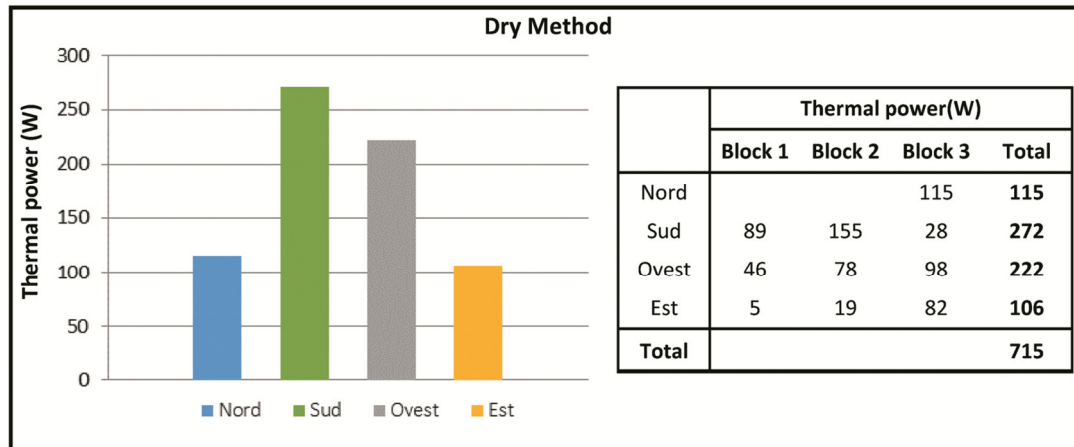


Figure 7: input conductive heat for Dry Method

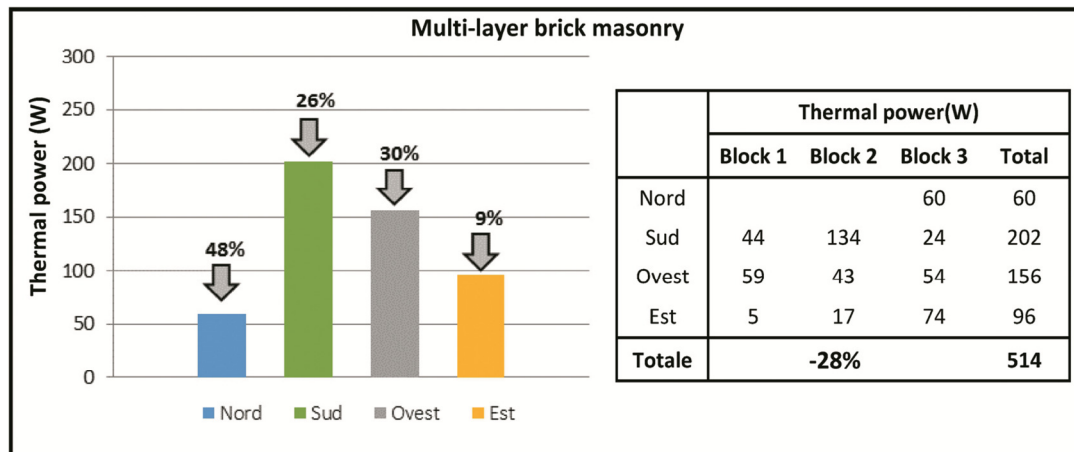


Figure 8: Comparison between Dry Method and Multi-layer brick masonry

Using the multi-layer brick method, (Fig.8) reduction of the loads is obtained, compared to the use of the dry method, in relation to the four orientations and ranging values from 10% to 48%. Varying a thermal power from 715W to 514W, there is a percentage decrease of 28%.

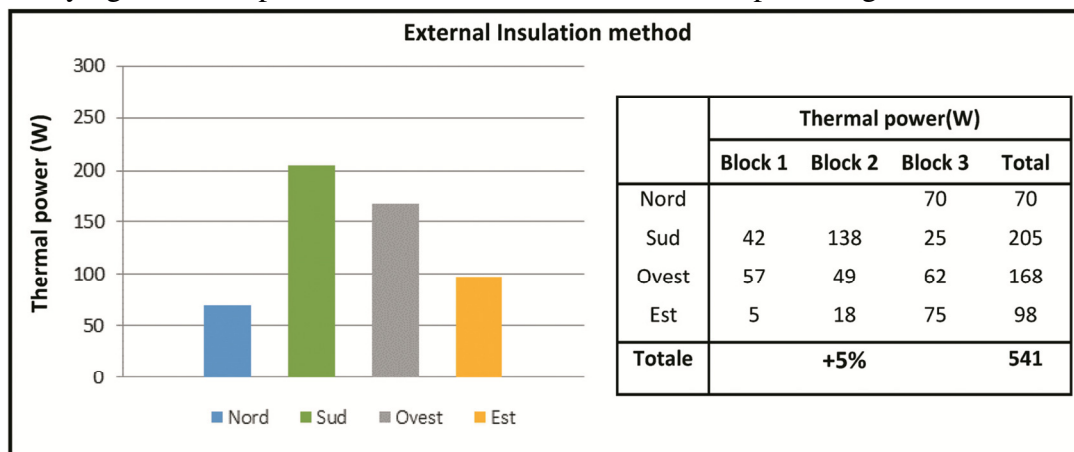


Figure 9: Comparison between Multi-layer brick masonry and Dry Method



Using the external insulation method, compared to the previous case, there is a percentage increase of 5%. Defining a final configuration of vertical closure, in this case, the external insulation method is preferred over the other solutions of opaque elements (Fig.9).

## **5. Numerical models and dynamic simulation**

It is possible to use model experimentation for predicting building spontaneous behavior in relation to varying contextual situations.

The analysis allows to improve the spontaneous building behavior in free floating during design phase.

It is created a virtual building model, thanks to the calculation engine Energy Plus. As a result, it is possible to check the behavior and the performance of vertical closures under dynamic condtions.

Through the analysis shown in Fig.10 (there is only August), it is possible to identify the critical hours because the operating temperature overflows from ASHRAE curves in buildings with natural ventilation.

Each point represents the operating temperature which is determined by a specific hour in the building in relation to an external temperature.

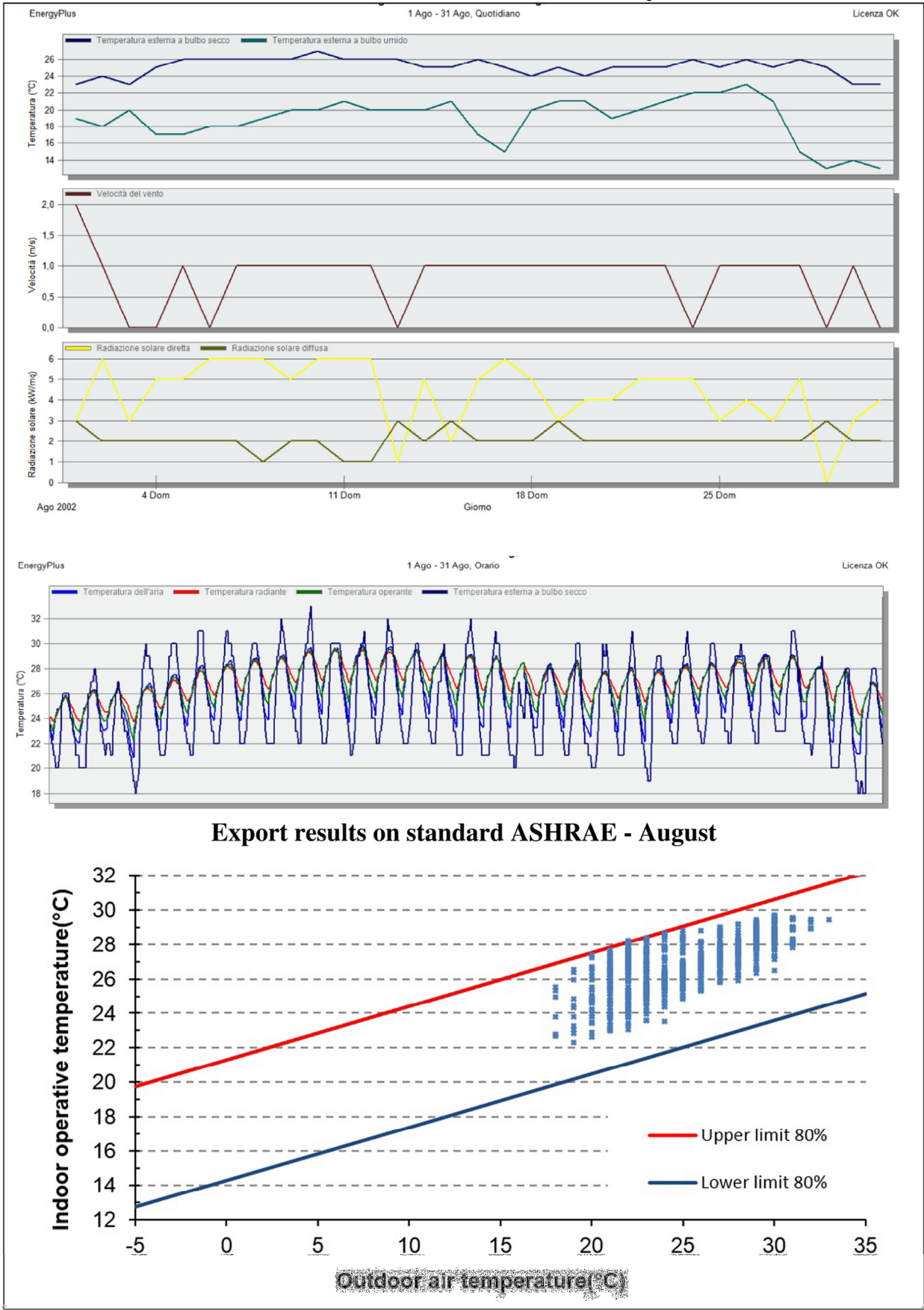


Figure 10: Graph of a project model with cooling spontaneous in a warm period.



## References

BRAGER, G.S., DE DER, R. *A new adaptive comfort standard for ASHRAE standard 55*, in Proc. Int. Conf. Moving thermal standard into 21<sup>st</sup> Century, Oxford Brookes University;

CROCE, S., POLI, T. (2007) *Case a basso consumo energetico, Strategie progettuali per edifici a climatizzazione spontanea in Italia*. Milano. Il Sole 24 ORE S.p.A..

CROCE, S. (2003) *Climate sensitive Building: a road map to centralise the sustainability in the architecture design*. Int. Conf. “Involucro quali messaggi di architettura”. Naples, 9-10 novembre

GROSSO, M. (1997) *Il raffrescamento passivo degli edifici*. Rimini. Maggioli.

IMPERADORI, M. (2008) *La progettazione con tecnologia stratificata a secco, realizzazioni innovative, linee guida e prodotti per una meccanica dell'architettura sostenibile*. Milano. Il Sole 24 ORE S.p.A..

[NICOL](#), F., [HUMPHREYS](#), M., [ROAF](#), S. (2012) *Adaptive Thermal Comfort: Principles and Practice*. London. Routledge.

RUDOLFSKY, B. (1979) *Le meraviglie dell'architettura spontanea*. Bari. Laterza.

IMPERADORI, M. (1999) *Le procedure Struttura/Rivestimento per l'edilizia sostenibile*. Milano. Maggioli.

This paper is written by the authors all together. In particular, the paragraphs n. 1, 2, 3, have been assigned to Gigliola Ausiello and the paragraphs n. 4, 5, have been assigned to Marco Raimondo.



## **Assessment Factors of Sustainable and Healthy Environment for Hot Spring Hotels in Taiwan**

### **Speakers:**

Chen, Hsing-Hao

China University of Science and Technology, Taipei City, Taiwan (Republic of China),

**Abstract:** *This paper collects the 78 initial assessment indicators of sustainability and health of physical environment for hot spring hotels in Taiwan by literature reviewing, and categorizes them into six assessment indicators groups as follows: “Sustainable Site”, “Water Resource”, “Energy”, “Health Environment”, “Pollution Prevention & Solid Waste” and “Facilities Maintenance & Safety Management”. Then we sieve 42 relatively important assessment factors from the initial indicators which belong to the appropriate indicators groups with the Fuzzy Delphi Method and collect the opinions from 40 experts. The specialties of the experts include “Building Environment”, “Water Resource”, “Tourism Management”, “Hot Spring Resource” and “Sustainable & Healthy Environment”.*

*According to the experts’ opinions, we get the priority of assessment factors for each indicator group. The result provides the reference for the owners and authorities to manage the physical environment and to reach the sustainability and health of the hot spring hotels in Taiwan.*

***Sustainability, Health, Physical Environment, Assessment Factor, Hot Spring Hotel***

### **Introduction**

Because of the location of Taiwan, the border of the Eurasian Plate and the Philippine Plate, the complicated geology results in plentiful hot spring resources. With the release of social environment and the people pay more attention to the leisure activities and health promotion, the development of hot spring tourist industry is blooming. A great deal of effort has been made on the hot spring quality and hotel management. What seems to be lacking, however, is a comprehensive assessment tool for sustainability and health of hot spring hotels’ physical environment.

The research tries to study the experts’ acknowledge about the importance priority of the environment of hot springs in the viewpoints of sustainability. The aim is to provide the reference for the authorities, the owners and the designers of hot spring hotels in Taiwan.

### **Methods**

This paper gets the initial assessment factors of sustainability and health of physical environment for hot spring hotels in Taiwan by literature reviewing. We collect the initial assessment factors from the review of the literature about “assessment tools of sustainable and healthy buildings”, “assessment tools of green and ecology hotels”, “assessment tools of hot spring environment” and “assessment tools of living space” etc. Furthermore, we integrate



and filter the initial assessment factors and categorize them into six assessment indicators groups as follows: “Sustainable Site”, “Water Resource”, “Energy”, “Health Environment”, “Pollution Prevention & Solid Waste” and “Facilities Maintenance & Safety Management”. The analysis and summary are shown as Figure 1.

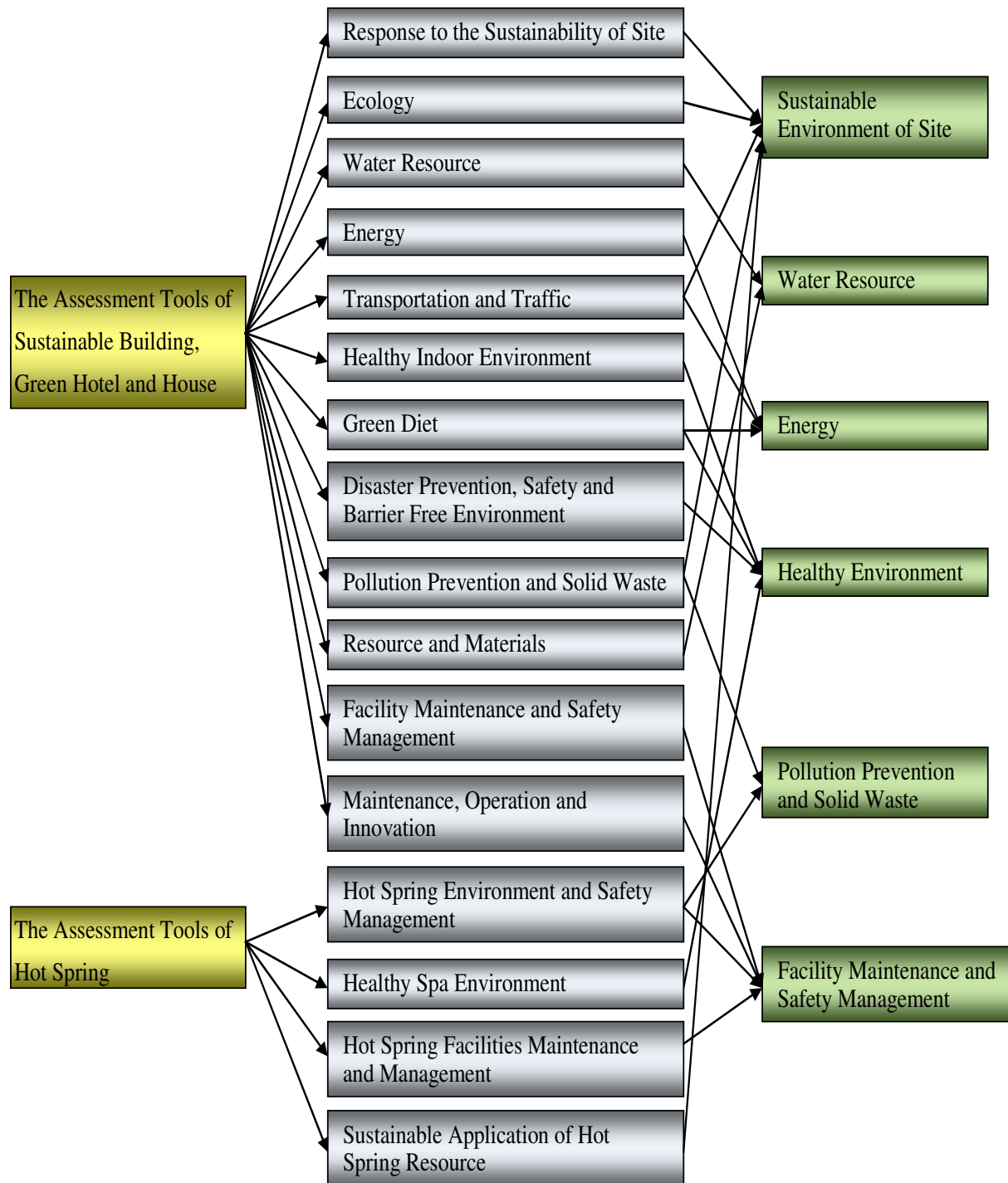


Figure 1 Forming of Assessment Indicator Groups



We use Fuzzy Delphi method to collect the experts' opinion about hot spring hotels. There were a total of 40 expert questionnaires distributed. The experts can be divided into two groups: "the academic group" and "the authority group". The academic group includes 10 hot spring experts, 9 experts whose speciality is architecture and 6 experts who specialize in leisure industry. The authority group includes 15 competent authorities from the north, middle, south and east regions of Taiwan. The total response rate is 82.5% and the effective rate is 75%.

### Results and Discussion

In order to get the individual importance evaluation of each assessment factor from all experts, the analysis of Reliability and Validity had been conducted. This study adopted the "Kolmogorov-Smirnov Test" to execute the reliability test for normal distribution and the pass rate of all initial indicators is 91%. That means all experts' opinions conformed the trend of consistency. The "Experience Rules" is applied to enforce the validity test for central tendency and the pass rate of all initial indicators is 87%. It presents the opinions from all experts meeting the central tendency.

First of all, we choesd 10% disagreement of all 30 effective experts questionnaires to be the threshold and deleted 20 initial indicators which were not agreed by more than three experts. Secondly, we calculated the triangular fuzzy number of each remaining initial indicator and presented the consensus of all experts by Simple Centroid Method. The triangular fuzzy number of each initial indicator is composed of "the minimum weight", "the geometric mean" and "the maximum weight". Then the triangular fuzzy number was transferred to the arithmetic mean and it would be the threshold of the initial indicator. The triangular fuzzy number of all initial indicators is (2.92, 7.26, 9.80), and the arithmetic mean of them is 6.66. So those initial indicators will be eliminated while their triangular fuzzy numbers are less than 6.66.

The indicator group of "Sustainable Environment of Site" should emphasize on "The Sensitivity of the Site", "Disturbance and Impact on the Site" and "Separate Drainage of Spring Water and Miscellaneous"(Shown in Table 1). The indicator group of "Water Resource" should emphasize on "Control of Hot Spring Flow", "Management of Water Use Efficiency" and "The Use of Water-saving Appliances" (Shown in Table 2). The indicator group of "Energy" should emphasize on "Natural Ventilation", "Good Shading Design" and "High-efficiency Lighting Control System" (Shown in Table 3). The indicator group of "Healthy Environment" should emphasize on "Prohibition of Toxic Substances", "Injection Location of Original Spring Water" and "The Overflow Device of Bath and Storage Tank" (Shown in Table 4). The indicator group of "Pollution Prevention and Solid Waste" should emphasize on "Environmental Sanitation Agents", "Dedicated Positions for Hazardous Waste Storage" and "Avoiding Plastic or Excessive Packaging Products" (Shown in Table 5). The indicator group of "Facility Maintenance and Safety Management" should emphasize on "Safety Inspection of Emergency Fire Fighting Equipment", "Safety Management to Prevent

Leakage and Explosion of Electrical Equipment” and “Structure and Facilities Security Check” (Shown in Table 6).

According to the experts’ opinions, we finally sieved the 42 assessment factors from the initial indicators and get the priority of assessment factors for each indicator group. The framework of assessment indicator groups and assessment factors of hot spring Hotel is shown as Figure 2.

■ :  $Dis \geq 3$ , ■ :  $Fuz \geq 6.66$  and  $Dis < 3$  (Dis: Disagreement, Mi: Minimum, Ave: the geometric mean, Ma: Maximum, Fuz: the arithmetic mean of the triangular fuzzy numbers)

Table 1 Fuzzy Numbers and Screening of Initial Indicators in the Group of “Sustainable Environment of Site”

Initial Indicators	Dis	Mi	Ave	Ma	Fuz	0	1	2	3	4	5	6	7	8	9
Environmental Impact Assessment	3	5	8.156	10	7.718										
The Generation of Pollutants	0	3	7.407	10	6.802										
Disturbance and Impact on the Site	0	6	7.831	10	7.943										
The Public Nuisance	2	2	5.831	10	5.943										
Adequate Green Space	4	4	7.031	10	7.010										
Response to Microclimate of the Site	6	1	5.097	10	5.365										
Decoration Materials	2	1	5.704	10	5.568										
The Sensitivity of the Site	2	6	8.585	10	8.195										
Separate Drainage of Spring Water and Miscellaneous	1	5	7.464	10	7.488										
Planting Native Species	0	2	5.481	10	5.827										
Multi-level Planting	8	3	5.502	9	5.834										
Protection of the Biotope	6	3	5.621	8	2.873										
The Application of Compost	4	2	4.944	9	3.831										
Location of the Spa Tanks	3	4	7.199	10	7.066										

Table 2 Fuzzy Numbers and Screening of Initial Indicators in the Group of “Water Resource”

Initial Indicators	Dis	Mi	Ave	Ma	Fuz	0	1	2	3	4	5	6	7	8	9
The Use of Water-saving Appliances	0	3	7.240	10	6.746										
Water Equipment with Sensors	3	3	6.780	9	6.260										
Management of Water Use Efficiency	0	3	7.268	10	6.756										
Gray Water Reuse System	1	2	6.623	10	6.207										
Rainwater Usage System	1	2	6.903	10	6.301										
Optional Laundry and Change of Linens	4	2	6.360	10	6.120										
Spa Recycling Equipment	6	3	6.654	10	6.551										
Control of Hot Spring Flow	0	3	7.321	10	6.773										
Public Pool Recycling Ratio	7	3	6.545	10	6.515										
Overflow discharge spring collection	6	3	6.739	10	6.597										
Original Spa Intermittent Supplement	0	1	6.663	10	5.887										

Table 3 Fuzzy Numbers and Screening of Initial Indicators in the Group of “Energy”

Initial Indicators	Dis	Mi	Ave	Ma	Fuz	0	1	2	3	4	5	6	7	8	9
Efficiency of Energy Use	1	3	7.536	10	6.845										
Using Energy-saving Products	0	5	8.101	10	7.700										
Natural Ventilation	0	5	7.971	10	7.657										
Good Shading Design	0	4	7.549	10	7.183										
Reasonable Lighting	0	5	7.292	10	7.430										
Installation of Heat Recovery or Insulation System	0	3	7.040	10	6.680										
High Efficiency Lighting Control System	0	5	7.554	10	7.518										
Application of Renewable Energy	1	2	6.155	10	6.051										



Table 4 Fuzzy Numbers and Screening of Initial Indicators in the Group of “Healthy Environment”

Initial Indicators	Dis	Mi	Ave	Ma	Fuz	0	1	2	3	4	5	6	7	8	9
Indoor Noise Control	1	4	6.981	10	6.993										
Indoor Natural Light	4	5	7.586	10	7.528										
Indoor Ventilation Rate and Comfort	3	5	7.808	10	7.602										
Healthy Indoor Air Quality Management Plan	0	4	7.823	10	7.247										
Springs Temperature Control of Storage Tank, Inlet and	2	4	7.346	10	7.115										
Healthy and Safe Indoor and Outdoor Environment	0	4	7.645	10	7.215										
Prohibition of Toxic Substances	0	6	8.185	10	8.061										
Management of Healthy Diet Environment	1	2	7.187	10	6.395										
Bath and Storage Tank Overflow Equipment	0	6	7.866	10	7.955										
Injection Location of Original Spring Water	2	6	8.069	10	8.023										
Cleaning and Disinfection Frequency of Hot Spring and	0	4	7.994	10	7.331										
Ensuring of Spring Quality	0	3	7.762	10	6.920										
Legionellosis Prevention	2	5	8.040	10	7.680										
The Independent Piping for interior and Exterior Spa	2	0	7.390	10	5.796										
The Proper Design of the Bath Overflow Tank and	0	3	7.666	10	6.888										
The Installation of SOS Bell or Siren	0	0	8.041	10	6.013										
Installation of Non-closed Drainage Holes in the Bath	1	5	7.634	10	7.878										
The Disaster Prevention and Escape Facilities	1	2	8.298	10	6.766										
Safety Management of Sensitive and Dangerous Area or	1	4	8.006	10	7.335										
Safety Management of Gas Releasing from the Hot	0	3	8.375	10	7.125										

Table 5 Fuzzy Numbers and Screening of Initial Indicators in the Group of “Pollution Prevention and Solid Waste”

Initial Indicators	Dis	Mi	Ave	Ma	Fuz	0	1	2	3	4	5	6	7	8	9
Resource Recovery Facility	0	3	6.395	10	6.465										
Dedicated Positions for Hazardous Waste Storage	1	3	7.236	10	6.745										
Using Recycling Products	2	2	6.596	9	5.866										
The Reuse & Recycle Plan	1	2	6.391	10	6.130										
Double-sided Copying	6	2	6.182	10	6.060										
Refillable Bottles	3	2	6.461	9	5.823										
Restrictions of Disposable Products	2	2	6.121	9	3.870										
Avoid Plastic or Excessive Packaging Products	2	3	7.056	10	6.685										
Environmental Sanitation Agents	0	4	7.560	10	7.186										
Storage Tanks and Water Towers are Isolated and	2	1	7.598	10	6.199										
Reuse of Existing Structures	3	3	6.339	8	5.779										
Reuse of Waste Materials	3	4	6.521	10	6.840										
Green Building Materials	3	3	7.391	10	6.797										

Table 6 Fuzzy Numbers and Screening of Initial Indicators in the Group of “Facility Maintenance and Safety Management”

Initial Indicators	Dis	Mi	Ave	Ma	Fuz	0	1	2	3	4	5	6	7	8	9
Equipment Safety Maintenance Management Plan	1	4	7.488	10	7.162										
Equipment Renewal Fessibility	1	4	6.940	10	6.980										
Functional Operation When Power Outage	0	2	7.004	10	6.334										
Safety Management to Prevent Leakage and Explosion	0	6	8.308	10	8.102										
Safety Management of Wire, Cable and Combustibles	2	5	8.008	10	7.669										
Management of Emergency Supply	0	3	7.950	10	6.983										
Safety Inspection of Emergency Fire Fighting	1	6	8.684	10	8.228										
Structure and Facilities Security Check	0	6	7.687	10	7.895										
Annual Safety Inspection of Mechanical Parking	4	4	7.491	10	7.163										
Gas Stove, Range Hood Safety Inspection	0	4	7.845	10	7.281										
Hot Spring Equipment Safety Inspection	0	5	8.207	10	7.735										
Material Selection of Hot Spring Equipment	1	3	7.551	10	6.850										

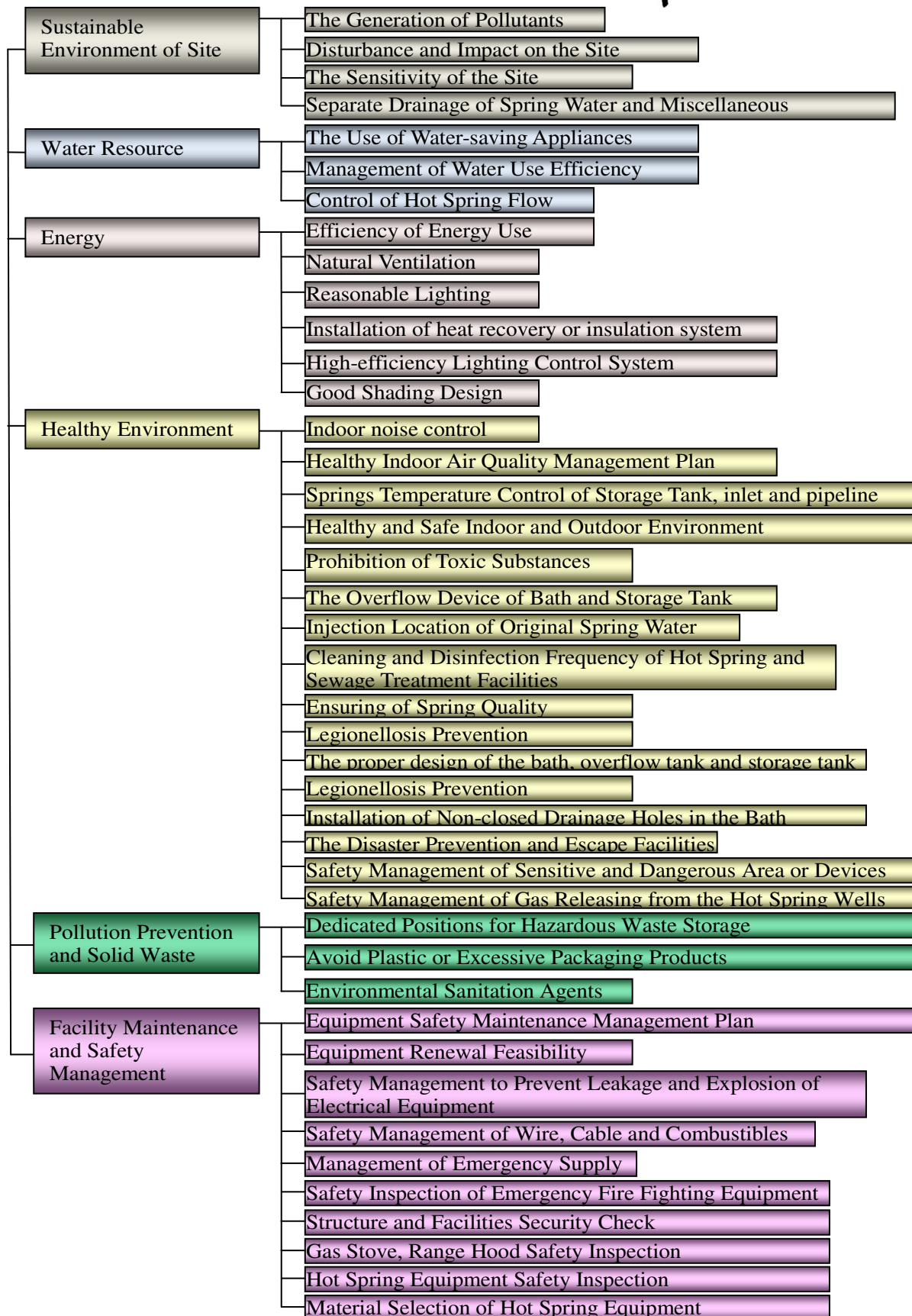


Figure 2 The Framework of Assessment Indicator Groups and Assessment Factors of Hot Spring Hotel





## Conclusions

This paper is aimed to sift the important assessment factors from the initial items according to the consensus of experts. According to the review of the literature, we summarized the assessment indicator into 6 groups: “Sustainable Site”, “Water Resource”, “Energy”, “Health Environment”, “Pollution Prevention & Solid Waste” and “Facilities Maintenance & Safety Management”. We can come to the conclusions as followed:

1. By Fuzzy Delphi Method, the study filtered 42 assessment factors which can be categorized into the appropriate assessment indicator groups, and we also get the importance priority of the assessment factors.
2. The top three assessment indicator groups which have more factors are “Health Environment”, “Facilities Maintenance & Safety Management” and “Energy”.
3. The “Health Environment” group focuses on the prevention of toxic substances, the quality of original spring water and the healthy factors of built environment. The “Facilities Maintenance & Safety Management” group focuses on the facilities operation management, safety management and disasters prevention. The “Energy” group focuses on the high-efficiency lighting control system, shading design and natural ventilation.

The results of this paper can be the database of the assessment tool for hot spring hotels’ environment and provide the key points for designing and managing the hot spring hotels in Taiwan.

## Reference

- [1]Chiang, C. M., Chen, H. H., Pan, Z. Q.. (2009). A Study on the Assessment Indicators for Physical Environment of Sustainable Campuses: The Case of Elementary Schools in Taiwan, *Journal of Architecture*, 67: 1-23.
- [2]Dubois, D., Prade, H.. (1980). Fuzzy sets and Systems: Theory and Application, New York, Academic Press, Inc
- [3]Ho, M. C. (2011). Evaluation Manual for Intelligent Building in Taiwan. New Taipei City: Architecture and Building Research Institute, Ministry of Interior.
- [4]Ishikawa, A., Amagasa, M. Etc., (1993). The Max-Min Delphi Method and Fuzzy Delphi Method via Fuzzy Integration, *Fuzzy Sets and Systems*, 5: 241-253.
- [5]ISO/TS 21931-1 (2006). Sustainability in building construction – Framework for methods of assessment for environmental performance of construction works– Part 1: Buildings. Switzerland: International Organization for Standardization.
- [6]Klir, G. J., Yuan, B.. (1995). Fuzzy Sets and Fuzzy Logic-Theory and Application, New Jersey, Prentice-Hall, Inc
- [7]Lasson, N..( 2007). Rating Systems and SBTOOL, iiSBE.

## **Integral Resilience – an indicator and compass for sustainability**

### **Authors:**

Peres, Edna (E)<sup>1</sup>; du Plessis, Chrisna (C)<sup>2</sup>

<sup>1</sup>University of Pretoria, Pretoria, South Africa

<sup>2</sup>University of Pretoria, Pretoria, South Africa

**Abstract:** *While established arguments suggest that the sustainability movement is not achieving enough and that its tools are falling short of ethical imperatives, there are few constructive solutions. This paper suggests that an integral resilience approach might propel the movement forward. Resilience theory has developed into various streams of inquiry and practice over the past forty years, offering a perspective to assess the strengths and weaknesses of a social-ecological system from which better decisions for the built environment can be taken. Apart from the useful clues that this externally quantifiable side of resilience offers, there is also the qualitative side of resilience, the internal dimension that guides decision-making. To effect sustainable change, both dimensions must be tackled. Using integral resilience both as an indicator of the quality of a place and a compass for making better decisions, tools can evolve to guide development.*

**Key words:** *integral theory, resilience, urban systems, sustainability*

### **Introduction**

The ‘green’ agenda side of the sustainability movement has resulted in an improvement in quantitative efficiencies of the built environment and an awareness of the need for different practices. However it is doubtful whether the awareness fostered is actually inspiring the deep ethical changes necessary in our consumption-hungry societies. It is consistently argued that the sustainability movement is not achieving enough [1][2][3][4] and in many ways sustains a destructive status quo. Current tools and rating systems furthermore fail to provide a meaningful response to the overwhelming number, scale and frequency of interconnected disasters set to cripple global social-ecological and economic systems during the 21<sup>st</sup> century [5][6]. The real issue is that the magnitude of these changes will force humanity to adapt to a very different world if it is to sustain itself. Mere redesign of current rating systems, such as that put forward by the Living Building Challenge, will not enable the transformation within the built environment necessary to retain a semblance of the life-style that society has become accustomed to. Rather what is required is alignment to a worldview that recognises change as inevitable and addresses the social-ecological aspects of sustainability with the same intensity as economic ones since, “we cannot exclude major dimensions of reality and expect comprehensive, sustainable results” [7]. For sustainability practice this change embodies nurturing the quality and diversity of life on earth, rather than simply sustaining and improving the damaging systems that perpetuate the status quo.

Green Building tools focus on reductive and prescriptive measures that improve the small-scale efficiencies of individual buildings and precincts. They do not consider the connections to broader built environment systems that change in response to fluctuating social-ecological conditions resulting from, for example, climate change; nor do they build capacity for resilience against an unpredictable future in which built environments will need to regenerate

and transform if they are to continue to sustain human life. By responding to today's problems, their focus is not on exploring and creating situations for green buildings or neighbourhoods to evolve in response to changing conditions, so that they may continue to provide quality habitats without intensive and expensive retrofitting. This paper proposes that sustainability assessments and practices can be improved through the adoption of a holistic and dynamic approach to development.

### **Bridging the gap – crossing the divide between ‘green’ and holistic sustainability**

The objective aspects of sustainability practice (such as ‘green’ behaviours or energy efficiency systems) are clear, however the subjective qualities, the deeper ‘why’ and ‘how’ questions, need to be considered as well [4]. If the responsibility of sustainability practice is to guide development toward prosperous habitats for all forms of life, then sustaining, and more importantly regenerating cities, necessitates building their capacity to absorb, adapt and evolve to changing conditions over time, without losing their functional identity [8] as thriving human (and non-human) habitats; it requires resilience. General rather than specific resilience of the urban fabric depends on complex structures that slowly unfold and evolve in order to develop strong internal connections like those seen in a leaf [9]. Principles for resilience (absorbing, adapting or transforming systems) and regeneration (the creative qualities that rebuild dysfunctional systems) can guide this progression of sustainability.

While resilience is increasingly being seen as a pathway to achieving sustainable development [10], its use as a valid theory for urban sustainability must be refined with a better understanding of its application to urban systems. The initial understanding of resilience was that it was a characteristic of a healthy ecological system which described the ability and speed of a system to return to equilibrium after a disturbance [10]. That understanding has since broadened into dynamic definitions that transcend the equilibrist approaches of its origins [10], and have developed further in the fields of ecology, psychology, business, emergency response, engineering, [6] and more recently urban systems [11]. Its application to cities has mostly focussed on anti-adaptive ‘bounce back’ attempts to manage or maintain the current condition of cities in the face of pulse disturbances like natural disasters or press disturbances like the economic recession. It can be argued that resilience theory provides a rich umbrella concept that may bring together a number of professions in the built environment and equip them with a common language [12] with which to find solutions for the unprecedented development demands of the 21<sup>st</sup> century. It holds potential to bridge the gap in discourse between various study areas, practices, professions and sciences that have traditionally been working in isolation, and through this process of integration a whole-systems approach to building the future of the city may be unlocked.

An urban system consists of a variety of interconnected and co-dependent relationships or networks which cannot be successfully isolated without compromising the integrity of the whole. In addition, a city does not only consist of what the eye can see, such as the physical buildings and services; it consists of spaces that hold intangible qualities for their citizens, like a unique ‘spirit of place’ or subjective meaning and identity. While built environment professionals focus almost predominantly on designing aspects of the city that can be seen,

they are most successful when they integrate the ‘hidden’ flows of experience and meaning pertaining to life-forms in the city, into their projects as well. Simply put, since a city is a whole-system of equally essential tangible and intangible aspects, similarly its resilience cannot depend on a singular perspective of resilience. Furthermore, this multiple perspectival framing of resilience becomes important in highlighting the additional understanding that resilience itself is not the goal. As an emergent characteristic of a system, it could be present both in highly functional systems or others which are dysfunctional. In this instance resilience would be perceived as positive in a functional system (say a healthy neighbourhood with amenities) or negative in a dysfunctional system (say poorly serviced informal neighbourhoods) and therefore resilience merely represents the capacity that a particular system has to absorb or adapt to pressures without collapsing. Using resilience theory to inform the study of urban systems therefore provides insight into which aspects of the system may need to be developed or collapsed in order to transform into more positive systems through regenerative design strategies [13]. However, the big challenge lies in being able to make responsible, holistic, aesthetic, just and precise decisions in response to what the resilience findings show. Integral Theory provides a useful framework within which to make such holistic decisions [7].

### **A whole-systems perspective of urban resilience**

In order to build the resilience of a regenerative urban system and sustain it over time, its tangible aspects (the physical fabric and structure) as well as its intangible aspects (the thinking that guides its development) must be enhanced. Traditionally, these realms of practice have been separated, with the focus in urban resilience lying in specific tangible responses and ‘bounce back’ approaches. However, since cities are complex-adaptive systems with multiple dimensions [14], an urban resilience strategy must take into account multiple resilience methodologies that each respond best to different situations. Holistic resilience practice in a city requires that both external and internal dimensions be tackled and developed, but without an overarching framework to guide its application, it may simply become another development ‘buzzword’. Over the past 37 years, an approach has developed with capacity to interrelate multiple dimensions of reality, offering possibilities for the successful holistic assessment and resolution of many 21<sup>st</sup> Century crises [7]. Using an Integral Theory framework to inform urban resilience practice can be the logical extension of existing research into the application of Integral Theory in the built environment such as sustainable architecture [4] and urbanism [15].

Integral Theory can be described as a full spectrum approach to the study and practice of life (in all its external and internal manifestations) that “attempts to create a comprehensive framework for understanding the complexity of multiple competing theories” [4]. The framework acknowledges objective (external and empirical) and subjective (internal and experiential) perspectives, as well as their manifestations in individual versus the collective domains (Fig. 2\_1, 2\_2). This results in four co-existing perspectives (quadrants or *quadrivia*) of life: behavioural, social, cultural and experiential terrains (Fig. 2\_3), each with its own unique wisdom that unfolds individually across a line of development that progressively

**1. SUBJECTIVE + OBJECTIVE PATHS**

INTERNAL PATHS	EXTERNAL PATHS
Conscious Meaning Worldviews Symbolism	Sciences Performance Ecology Context

**2. INDIVIDUAL + COLLECTIVE VALUES**

INDIVIDUAL PATHS	Individual parts
COLLECTIVE PATHS	Complex wholes

**3. ALL QUADRANT OF THE PRIMARY VALUE SPHERES**

	INTERNAL PATHS	EXTERNAL PATHS
INDIVIDUAL PATHS	I EXPERIENCE	IT BEHAVIOUR
COLLECTIVE PATHS	WE CULTURES	ITS SYSTEMS

**4. ALL LEVELS OF CONSCIOUSNESS + DEVELOPMENT**

	INTERNAL PATHS	EXTERNAL PATHS
INDIVIDUAL PATHS	SPIRIT MIND BODY SUBTLE	CAUSAL GROSS
COLLECTIVE PATHS	ME ALL US	GROUP NATION GLOBAL

## Building the resilience of thriving urban systems through an integral approach

Urban systems can be interpreted through the four different perspectives of the integral *quadrivia*, and within each quadrant resilience theory applications will differ. For example,



the external paths of a city manifest in the following ways (Fig. 3\_1). Buildings, organisms, infrastructure, typologies and morphologies, all of which can be measured and quantified, would be located within the terrain of behaviours. Political, economic, social, legal, institutional, and educational structures would be found in the terrain of systems where they have manifestations in architectural styles [17]. Behaviours and systems are usually the aspects within which sustainability practices tend to focus, trying to force behaviours into optimal efficiencies or systems into representations of the whole of reality. However, these strategies exclude the internal paths which are essential to the healthy resilience and therefore sustainability of a city. Worldviews and ideologies held by groups can be found in the terrain of culture, and these values give rise to architectural identity and a ‘sense of belonging’ that a community or individuals associate with the built form in the city (Fig. 3\_1). Lastly, in the terrain of experience, beliefs and emotions take root in the phenomenological states that give rise to experiences of ‘spirit of place’ and poetics in landscape [7].

Engaging resilience within each terrain requires shifting between the different resilience practices mentioned earlier in the paper, determined by where their methodologies offer the most appropriate responses (Fig. 3\_2); for example, in the external paths, the design of a road will require resilience approaches that can mitigate known disturbances and can accommodate for a variance on the standard through ‘bounce-back’ and equilibrist engineering resilience. In the case of systems, mapping the impacts of climate change disasters on the health, political security, economy and social interactions within city networks requires an appreciation of various types of systems-based resilience practice. When dealing with internal paths (Fig. 3\_2), on a collective scale, the resilience of cultural norms or political ideologies affect the resilience of a community’s beliefs or worldviews. This in turn impacts on how they identify with built environments and consequently affects their actions in the external terrains. In the case of experiences, the presence of ‘spirit of place’ and the quality of phenomenological exploration and emotion becomes important, and in this case, psychological resilience can provide clues for creating spaces that can evolve an individual’s consciousness development within carefully crafted environments.

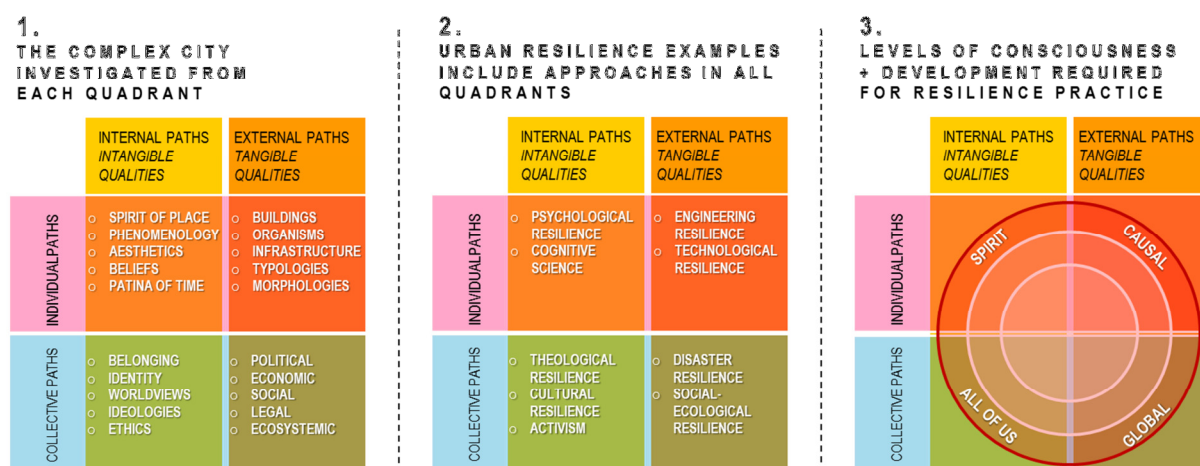


Figure 2- Integral Urban Resilience: All-Quadrants & All-Levels (Authors,2014); based on (Esbjorn-Hargens, 2012) (Zolli & Healy, 2012)

Lastly, the interpretation and application of resilience theory in the urban realm, requires a certain level of conscious development within the internal paths. It is suggested that individuals at least evolve beyond thinking only about themselves, their family or their tribe, to a higher more complex level at which they are able to operate in an organisation or community that encompasses various groups [15]. Sustainability requires that individuals should be able to think beyond this intermediary scale toward global eco-systems and networks (Fig 3\_3: All of us and Spiritual). This higher level of development requires individuals to step well outside of themselves in order to achieve a greater depth of understanding and points of engagement with individuals who are still engaging with sustainability at community or organisation levels. Communities and groups also need to be guided to evolve their average operational centres to higher levels of empathy and away from self-centred goals. In addition, external paths also have levels of development which increase in complexity at each level by transcending and including local vernacular wisdom, knowledge and strategies from lower levels (Fig 3\_3: Global and Causal). Local vernacular wisdom is necessary because it is based on a social-cultural worldspace to which societies tacitly conform, and also determines individual and collective behaviours in the practice of sustainability [4]. Practices should tap into and then transcend the current predominant worldview of a particular region. Integral urban resilience theory has to foster development along internal and external paths toward these highest levels of development and beyond, if it is to ensure the resilience of truly sustainable social-ecological habitats.

## Conclusions

We know we are not doing enough. In response to the conference's question regarding the adequacy of current tools and rating systems, this paper argues that they are inadequate and that they are so because they focus on monitoring and awarding exterior paths and disregard interior paths of development. An integral urban resilience approach offers the opportunity to move away from restrictive 'green' checklists, toward a way of thinking that promotes a holistic reassessment of the goals of sustainability and outlines paths for reaching them. Integral resilience requires that practitioners ask the right values-based questions (interior paths), especially since built environment professionals have the ethical responsibility to design human habitats for future generations that enable the health and co-existence of all forms of life. To create these environments requires an understanding of the system and its empirical conditions (exterior paths). Tools (and checklists if unavoidable) can then be aligned to a combination of both these paths; an integral urban resilience approach embraces the qualities of life from all its perspectives. Developing this approach forms the next step that can enable an evolution of the sustainability movement, enabling the development of built environments driven by an ethical imperative to promote innovative systemic regeneration: to do more good, do it truthfully and beautifully.

## References

- [1] Meadows, D., Meadows, D.L., & Randers, J. (1992). *Beyond the Limits: Confronting global collapse, envisioning a sustainable future*. Vermont: Chelsea Green Publishing Company.

- [2] Fox, W. (Ed.). (2000). *Ethics and the Built Environment*. London: Routledge.
- [3] Brown, B. (2005). Theory and Practice of Integral Sustainable Development. *Journal of integral theory and practice*, 2(1), 1-70.
- [4] de Kay, M. (2011). *Integral sustainable design: transformative perspectives*. London: Earthscan. p.12
- [5] Gilding, P. (2011). *The Great Disruption: How the climate crisis will transform the global economy*. London: Bloomsbury.
- [6] Zolli, A., & Healy, A. (2012). *Resilience: why things bounce back*. London: Headline Publishing Group. p.21.
- [7] Esbjörn-Hagens, S. (2012). An overview of integral theory: an all-inclusive framework for the 21st Century. *MetaIntegral Foundation, Resource Paper No.1*, June, 1-20. p14-15, 6.
- [8] Walker, B., & Salt, D. (2012). *Resilience Practice: building capacity to absorb disturbance and maintain function*. Washington: Island Press. p. 3.
- [9] Salat, S. (2011). *Cities and Forms: On sustainable Urbanism*. Paris: Hermann. p. 465.
- [10] Davoudi, S. (2012). Resilience: a bridging concept or a dead-end? *Planning Theory & Practice*, Vol. 13, No. 2, 299-333.
- [11] Anderies, J. (2014). Embedding built environments in social–ecological systems: resilience-based design principles. *Building Research & Information*, 42(2), 130–142.
- [12] Brand, F., & Jax, K. (2007). Focusing the Meaning(s) of Resilience: Resilience as a Descriptive Concept and a Boundary Object. *Ecology and Society*, 12(1):23. p. 23.
- [13] Hes, D., & du Plessis, C. (2014). *Designing for Hope: pathways to regenerative sustainability*. London: Earthscan by Routledge.
- [14] du Plessis, C. (2008). Understanding Cities as Social-ecological Systems. In: *Proceedings of World Sustainable Building Conference – SB’08, 21-25 September*. Melbourne, Australia.
- [15] Hamilton, M. (2008). *Integral City: Evolutionary Intelligences for the Human Hive*. Gabriola Island, Canada: New Society Publishers. p. 245.
- [16] Wilber, K. (1996). *A Brief History of Everything*. Boston : Shambhala. p. 311.
- [17] Esbjörn-Hagens, S., & Zimmerman, M. (2009). An overview of integral ecology: A Comprehensive Approach to Today’s Complex Planetary Issues. *Integral Institute, Resource Paper No.2*, March,1-14.

## **Residential areas retrofitting towards nearly Zero Energy Districts (nZED). A case study: Valladolid-Cuatro de Marzo**

García-Fuentes, M. Á.<sup>1</sup>; Vasallo, A.<sup>1</sup>; García-Pajares, R.<sup>1</sup>; Pujols, W. C.<sup>2</sup>; Meiss, A.<sup>3</sup>

<sup>1</sup> Fundación CARTIF, Valladolid, Spain

<sup>2</sup> ACCIONA Infraestructuras, Madrid, Spain

<sup>3</sup> Universidad de Valladolid, Valladolid, Spain

**Abstract:** *Although the concept of nearly Zero Energy Buildings is well established among the new Buildings sector, in retrofitting processes it is necessary to think about integrated solutions at district level, leading to the new concept of nearly Zero Energy Districts. By following this new approach, the spectrum of Energy Conservation Measures (ECMs) that can be applied is wider. As a result, more ambitious objectives can be potentially achieved at urban scale. This paper introduces a Methodology for Energy Efficient Residential District Retrofitting, easily replicable in EU. Its application to the Cuatro de Marzo district in Valladolid (Spain) is depicted, focusing on the analysis and diagnosis of the current status of the district and the selection of the optimal combination of ECMs to be applied. This selection is based on a set of sustainability key performance indicators defined and calculated through the whole process.*

***District, retrofitting, energy efficiency, nZED, methodology, replicability, indicators, IPD***

### **1. Introduction: the Nearly Zero Energy District (nZED) concept**

The energy consumption in buildings is a key factor of environmental impacts as the energy use in buildings accounts for approximately 40% of the energy consumption and 36% of CO<sub>2</sub> emissions [1]. Since the EU aims at reducing the energy consumption and GHG emissions, the building stock plays a major role and the European Commission, under the Energy Efficiency Plan (Directive COM/2011/370), has identified the energy efficiency in buildings as a priority action in achieving the 20-20-20 strategic targets [2]. The necessity of developing new methodologies and better business models to address projects for accelerating the urban regeneration towards nZED has become an indubitable issue in the recent years.

In this context, the European project R2CITIES aims at developing and validating an integrated and systemic methodology for energy retrofitting at urban scale, achieving a methodological and scientific instrument able to support the implementation of solutions at district level. The main objective is to optimize the integral solution, following a holistic approach, to reach high levels of energy performance improvements while being cost-effective and therefore, more capable of been bankable.

This paper presents the application of this methodology to an area of the “Cuatro de Marzo” district, located in Valladolid, with two building typologies presenting a high level of energy consumption and low comfort conditions.

### **2. Identification of barriers and opportunities: the energy discussion in residential areas of the 50-80s in Spain**

In the middle of the 20<sup>th</sup> Century, an important migratory movement from villages to cities

occurred in Spain as a consequence of a retarded industrialization process, emerging a drastic need of new dwellings. During this period, private promotions were not capable of covering the existing demand due to the economic situation. Aiming at solving the great demand of new houses, many public dwelling promotions in the 50-80s were executed in a very short time following a unique project. These integrated projects followed the principles of the hygienic housing and recurrent constructive and aesthetic solutions, resulting in homogeneous areas with typologies that are always of open blocks and towers. All these issues, along with the application of the International Style language and the technological and materials precariousness, allow to explain the deficiencies that are present in these buildings [3].

Under this scenario, apart from the great potential of energy savings and improvement of comfort conditions, the next premises must be considered; the great amount of grey energy already stored in these buildings, their conditions of centrality, urban infrastructures, mix of uses and social cohesion [3]. Considering also the typological and constructive homogeneity of these districts, the necessity of developing systemic and integrated solutions is clear, being easily replicable along the whole district, reducing costs and execution times.

Although technological barriers are reduced at district level due to the wide range of applicable ECMs, economic and legal barriers are usually increased. The most important barriers in Spain are inherited from the housing policies, which have been focused on new buildings without coordination with the urban planning regulations. In this scenario, some regulations still remain out-dated, hindering the comprehensive rehabilitation of the building stock. Therefore, there is a strong need for administrative coordination in order to update the regulatory framework. Finally, the critical size of the interventions and the establishment of economies of scale is a key factor for the feasibility and success of this kind of projects [4].

### **3. District energy retrofitting towards nZED – methodology and strategies**

Under these premises, R2CITIES presents a systemic and integrated methodological tool based on a set of District Sustainability Indicators (DSIs) that allow the evaluation of the district status at different phases, ranging from the diagnosis of the current situation, the combinations of technologies, as well as the quantification of energy savings to finally, the improvement in comfort conditions. This methodology considers the change of scale from buildings to districts aiming at implementing scalable measures able to reduce timing and costs while supporting the exploitation of the urban morphology for this objective.

Although the passive measures are applied at building level, the district concept affords cost reduction in both project and execution phases through the greater scale. On the other hand, active measures can be implemented from a district perspective achieving higher energy efficiency in order to meet the nZED objectives [5]. The advantages of considering the district as a global energy unit are based on the improvement of efficiencies through the implementation of centralized heating or cooling systems, the exploitation of different slopes and tiles for solar technologies or the utilization of common and public spaces for the installation of Renewable Energy Sources (RES) technologies to cover the demand.

#### **3.1. Definition of District Sustainability Indicators (DSIs)**

Following the proposed methodology, the definition of the DSIs is a key factor in order to



evaluate the success of the retrofitting processes. These parameters refer to the data types that are measured or estimated in relation to a defined measurement boundary for verifying the impact of the ECMs and cover in a quantifiable manner energy, comfort, and environmental technical indicators together with economic, social and urban conditions. DSIs are specifically defined for considering the district as a global energy unit where energy and emissions are balanced globally and have been defined following the recommendations of the CONCERTO Premium guidelines [6].

In the context of the proposed methodology there exists a logical evolution in the indicators that are calculated for the whole project. The status of each indicator is identified at each specific stage, starting from the diagnosis at district level to the final energy savings, economic and social assessment stage, to support the process of design, execution, evaluation and decision-making of the most cost-effective and suitable combination of technologies.

### 3.2. *R2CITIES: A 4-step methodology towards District Retrofitting*

The phases covered by the methodology are similar to any retrofitting process (Figure 1): (i) district audit, (ii) concept and detailed design, (iii) implementation of the construction works, and (iv) measurement and verification of energy savings, together with the assessment of the other DSIs, and acceptance plan.

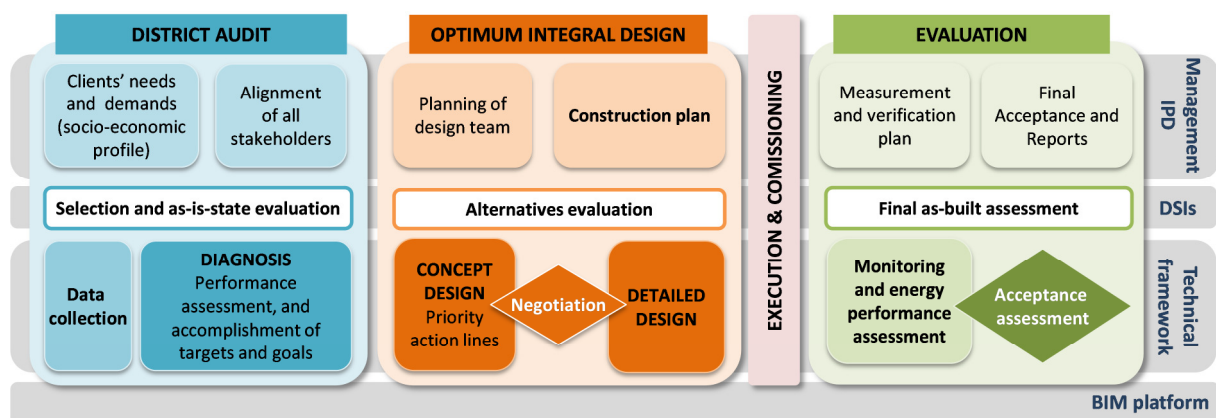


Figure 1: R2CITIES methodology for District Retrofitting

The main innovative aspect of the methodology derives from the utilization of the Integrated Project Delivery (IPD) concept through Building Information Modelling (BIM) principles in order to improve the efficiency during all the phases of the retrofitting process and optimize the project results. Following this holistic approach based on IPD principles, all stakeholders cooperate in a collaborative manner through all phases, especially at the commissioning of Energy Conservation Measures stage. This enhanced process results in an intensive quality control plan, covering the whole process, aimed at improving the quality of the designed solutions, enhancing the design conformance to the clients' needs and demands and ensuring high and functional quality of the final intervention. BIM tools are used to support this multi-faceted collaboration, but also to store all the information of the district and the retrofitting process during the methodology life cycle.

**Step I - District Audit.** The first phase, diagnosis, is supported by the utilization of Energy performance simulation tools and methods aimed at quantifying each DSI as per current

conditions of the district. A preliminary set of goals is defined, at this first stage, considering the client needs and demands. Data collection from different sources allows its quantification through energy performance simulations, monitoring and testing of certain parameters, non-destructive testing, analysis of energy contracts, or the distribution of questionnaires to owners to determine comfort, social or economic aspects. All these data are processed and DSIs are quantified through standardized calculation methods. Once the diagnosis phase has been completed, objectives and goals are reviewed to be aligned with the client needs. The ambition of these goals is determined by the barriers, especially those non-technical related to legal aspects and economic feasibility. To align client demands to technical or normative aspects, the involvement of all stakeholders during the establishment of goals is essential.

**Step II – Evaluation of ECMs and optimum integral design.** This phase starts with the concept design and finalises with the detailed design. In between, it is placed the negotiation process, which is the core of this second step. At this stage, sets of combined technologies are evaluated by simulation tools and calculation methods in terms of the defined DSIs. To decide the implementation of the most suitable set of technologies it is strictly necessary the definition of attractive financial models, which must be agreed with building owners. By considering all buildings of the district and the combination of technologies as a whole, the Return of Investment (ROI) can be reduced making the intervention more feasible under a specific investment plan. Thus, while for passive measures the existing returns of investment are assumable with difficulty when combining passive and active strategies ROI values are substantially improved.

**Step III – Implementation of the construction works, operation and maintenance.** The methodology is completed with the implementation of the construction works and the district commissioning, along with the verification of the achievement of those goals defined in the previous phases. Under traditional methods, in this phase new agents appear for the construction works or building management. In that sense, the IPD based methodology ensures that all stakeholders are present in the decision making process. In this process new barriers appear, especially related to the level of implementation of certain technologies or normative at district level. For that reason, this methodology intends to contribute to leverage normative under development as the European Directive of Public Procurement decrees regarding the future use of BIM for all works under a public contract.

**Step IV – Measurement and verification of energy savings and acceptance plan.** Due to the high cost to implement the ECMs and the expectation that they will reduce energy use, energy renovation programs at district level require careful evaluation. Energy, water or demand savings cannot be directly measured, since savings represent the absence of the use of these sources. Savings can be addressed by adopting suitable M&V protocols (e.g. International Performance Measurement and Verification Protocol -IPMVP- [7]) to compare measured use before and after the implementation of ECMs, making suitable adjustments for changes in existing conditions.

#### **4. Concept application in a case study: Valladolid-Cuatro de Marzo district**

Projected in 1955 at the periphery, “Cuatro de Marzo” district is currently located at the end

of the main boulevard of Valladolid. The district is part of 6,473 dwellings promoted in Valladolid between 1940 and 1967 by the National Housing Institute (INV) and the Housing Union (OSH). Characterized by a high population density (200 inh./Ha.) and high construction density (100 dw./Ha), buildings are multifamily and multi-property. Also, a residential commonhold is established among all the flat-owners in each building to manage the common parts of the buildings.

The retrofitting plan in the district is being promoted by the Municipality of Valladolid. Specifically, the municipal-owned company for ground and dwelling ("Sociedad Municipal de Vivienda y Suelo de Valladolid (VIVA, S.L)") will play the role of coordinator/supervisor of the refurbishment works and will articulate the negotiation with the owners to join to the retrofitting urban plan.

#### ***4.1. District audit and identification of barriers***

At this stage of project implementation, the first phase of the methodology has been applied in the district, covering the detailed diagnosis and audit report of this area under the methods and tools described within the methodology. Thus, energy and comfort conditions have been evaluated while defined the social, economic and urban aspects in order to establish the main targets and goals to be achieved through the intervention process accompanied by a detailed analysis of the main barriers identified.

In order to evaluate the DSIs, energy performance simulations have been performed to characterize energy and comfort aspects, complemented by the data collected among the owners to evaluate the remaining indicators. For this purpose, a set of questionnaires have been distributed to the inhabitants, collecting aspects related to their profiles of use of the energy systems, the energy consumptions of the last year, their comfort perception, as well as social (e.g. age, social cohesion, etc.) and economic aspects (rent levels, unemployment rate, etc.) All these data have been collected and processed to quantify the DSIs under the R2CITIES principles as shown in Table 1.

In terms of energy and comfort conditions, through the combination of energy performance simulation tools (Design Builder and Ecotect) and non-destructive testing (IR thermography and pressurization test) the main deficiencies have been characterized and a validated energy performance model has been defined to be used during the evaluation phases.

The main problems detected in these buildings are due to the lack of insulation in the envelope, appearing also thermal bridges that in some cases provoke condensation problems. Also, although some dwellings have been renovated and do not present this problem, in most of dwellings there are high infiltration levels in windows that are similar to the levels existing in all building of this age.

Specific barriers were detected when evaluating the social aspects. The majority of the residents are using the dwellings as a principal house, being around 19% of empty houses. The population is relatively aged, being the percentage of old people 28.8%, while the percentage of young people is only 9.9% and the average age is 53 years old. The fact that almost one third of the inhabitants are pensioners, together with the high level of

unemployment, approximately 20%, may result in a serious barrier in the negotiation phase. Therefore, these conditions make necessary the development of attractive business models, accompanied by an intensive awareness campaign in order to show the benefits of the renovation plan, not only in energy terms, but also in economic benefits in the long term.

After the completion of the diagnosis phase, a first approach to the ECMs that can be implemented to achieve the goals (60% of total energy use reduction and 60% of global CO<sub>2</sub> emissions reduction) while overcoming the identified barriers has been carried out.

#### 4.2. Evaluation of ECMs and optimum integral design

In a first approach to the conceptual integral design, sets of ECMs were evaluated in terms of the DSIs defined in the methodology framework. These measures consider the improvement of the envelope insulation, by combining External Thermal Insulation Composites and ventilated façades including active measures for energy production (i.e. Building Integrated Photovoltaic). For the thermal production, a centralized heating system based on a biomass boiler is evaluated, while an improved control system for balancing the energy flows is also considered within the set of measures to be implemented. Table 1 summarizes the current and expected conditions in terms of energy, CO<sub>2</sub> and costs savings.

Table 1: Summary of District Sustainability Indicators under evaluation

District Sustainability Indicators		as-is-status	foreseen status
ENERGY	Density of final thermal energy demand	111.52 kWh/m <sup>2</sup> yr	66.91 kWh/m <sup>2</sup> yr
	Density of final energy consumption	194.20 kWh/m <sup>2</sup> yr	95.02 kWh/m <sup>2</sup> yr
	Peak load of electricity demand	8.37 kW	6.45 kW
	Peak load of thermal energy demand	26.43 kW	15.85 kW
	Degree of energetic self-supply	0 kWh/kWh	0.6 kWh/kWh
	Degree of accordance with national laws	27.28%	-
ENVIRONM.	Greenhouse gas emissions	43.45 kgCO <sub>2</sub> /m <sup>2</sup> yr	10.90 kgCO <sub>2</sub> /m <sup>2</sup> yr
SOCIAL	Average age of inhabitants	53 years old	-
	Number of households that are unemployed	20%	-
	Ownership structure	Multi-property	Multi-property
ECONOMIC	Energy expenses for heating and DHW	822.14 €/yr/dw	298.01 €/yr/dw
	Energy expenses for lighting in dwellings	314.78 €/yr/dw	252.29 €/yr/dw

Considering the package of technologies under analysis, active measures to be implemented (i.e. biomass centralized heating and DHW system and PV technologies) becoming an attractive model for the participation of an ESCO. Through this model, in which part of the total investment will be subsidized by the Municipality and the EU Grants, a company could be in charge of the remaining part of the investments, establishing an energy contract with the building owners. Also, when combining the passive and active measures, advanced business models appear, where the establishment of an association of a Construction Company and an ESCO, following a shared-risk model, can offer a more attractive product to the owners, establishing a long-term financial plan to facilitate the negotiation.

## 5. Discussion and conclusions

When addressing retrofitting processes in large urban areas, the implementation of the nZED concept leads to the development of new holistic and systemic methodologies. The R2CITIES methodology, based on the IPD principles and supported by the BIM concept, will improve the whole value chain, aiming at reducing the costs and timing of the whole process. These benefits, added to a wider scale, will make feasible and bankable the interventions.

Those barriers to the widely application of the methodology have been identified. In particular, the main barriers found in the “Cuatro de Marzo” district are related to economic and social aspects. A significant part of the investment cost must be covered by the owners; therefore, the negotiation phase is essential. Moreover, the technological package bid from conceptual design should not be only attractive in terms of energy savings to ensure public subsidies but also economically feasible to assure the positive involvement of the owners.

A set of passive and active ECMs has been defined to ensure the energy savings when retrofitting the district. This strategy also contributes to an improvement of the ROI by delivering new shared-risk models through the combination of financial entities, ESCOs, construction companies or other possible public or private investors being in charge of the initial investment needed, and establishing medium or long-term contracts with the owners.

From this evaluation, it has been detected that there is a strong need for administrative coordination in order to update the regulatory framework, aiming at making easier the promotion of these integrated retrofitting plans at urban scale to achieve the nZED objectives.

## 6. Acknowledgements

This research work has been funded by the European Commission through the 7<sup>th</sup> Framework Programme, under the research project R2CITIES, *Renovation of Residential urban spaces: towards nearly zero energy CITIES*, Grant Agreement n°314473.

## 7. References

- [1] Lewis, J.O., Hógáin, S.N., Borghi, A. (2013). Building energy efficiency in European cities, Cities of Tomorrow - Action Today. URBACT II Capitalisation
- [2] COM(2011) 370. Final proposal for a Directive of the European Parliament and of the Council on energy efficiency and repealing Directives. European Commission, Brussels.
- [3] Meiss, A., Del Caz, R. & Álvaro, A., (2013). Rehabilitación de barrios de vivienda social. El ARI de la Rondilla en Valladolid. Ciudad y Territorio. Estudios Territoriales CyTET XLV (175) 2013. Ministerio de Fomento, Madrid.
- [4] Gee, L., Dijol, J. (2013). Financing Nearly Zero Energy Housing Projects. Power House Nearly Zero Energy Challenge. NHF & CECODHAS Housing Europe, Brussels.
- [5] García-Fuentes, M.A., Pujols, C., García-Pajares, R., Vasallo, A., Martín, A. (2013). Metodología de Rehabilitación Energética hacia Distritos Residenciales de Energía Casi Nula. Aplicación al barrio del Cuatro de Marzo (Valladolid). II Congreso EECN, Madrid.
- [6] <http://concerto.eu/concerto/about-concerto/about-con-intro.html>
- [7] International Performance Measurement and Verification Protocol, Volume I





## **The role of the urban support in the regeneration of vulnerable neighbourhoods.**

### **Speakers:**

Garcia Madruga, C<sup>1</sup>, Hernández Aja, A<sup>2</sup>.

<sup>1</sup> Department of Urban and Regional Planning, Technical University of Madrid, Madrid, Spain

<sup>2</sup> Department of Urban and Regional Planning, Technical University of Madrid, Madrid, Spain

**Abstract:** *The processes of social and urban segregation have got worse during the last decades. Several studies have deepened into the analysis of the causes and consequences of these processes and have tried to define solutions that beyond eradicating some specific problems, were aimed at the consolidation of sustainable urban environments.*

*This paper presents an approach to the problem of urban inequality based on the concept of urban vulnerability as something that goes beyond the social and economic problems. In exclusion processes it is very important to consider the urban context and the physical and structural conditions not only in each neighborhood but also in the city as a whole. The paper seeks to pose a reflection on the urban support, which is understood in all its complexity and thought to be a key to ensure access and the right to the city of the citizens most in need.*

**Keywords:** *Urban vulnerability, accessibility, urban assets, urban support*

### **Urban vulnerability and segregation within current context**

The economic growth, that took place in Spain from the nineties till 2008, brought along huge economic and redistributive consequences. Always linked to a real estate risk and to the removal of capital from the lowest income families, this growth became into a mechanism of accumulation-dispossession suffered by the most disadvantaged social classes. Several studies, in which the socio-spatial segregation was analysed through the evolution of housing prices (as a proxy index for income), demonstrated the progressive and ongoing gentrification of certain areas of the city in contrast to the constant exclusion of the most vulnerable districts (1).

Furthermore, in 2008 the 6th Report on Spanish exclusion and social development (2), pointed out that since the 90s the investment on social spending in relation to GDP growth had been reduced, from the 24.4% to the 20%. In recent decades, and more intensively because of the financial crisis and the continuous austerity policies, we are being witnesses of an accelerated dismantling of public goods and services, which suffer not only from drastic budget cuts but from privatization actions as well.

These processes of capital transference and accumulation have had profound effects upon the city. The last Analysis of Urban Vulnerability in Spain (3) revealed that inequality and urban segregation did not improve during the first decade of economic boom. Instead of that, it

increased. According to this analysis, people living in vulnerable neighborhoods during the inter-census period 1991-2001 increased by 50.2%. Comparing the analysis conducted in 1996 (based on 1991 census) and the one conducted in 2011 (based on 2001 Census), the number of vulnerable neighbourhoods went from 378 to 604 in a decade.

In cities like Barcelona or Madrid, the growth of urban vulnerability was even more remarkable. In the first one, the number of neighbourhoods rose from 12 to 45, which represented an increase of 36.3% in the population living in vulnerable neighbourhoods. In the case of Madrid, the figures were even more striking. The number of vulnerable neighbourhoods grew more than doubled going from 183.531 to 605.153 of vulnerable people.

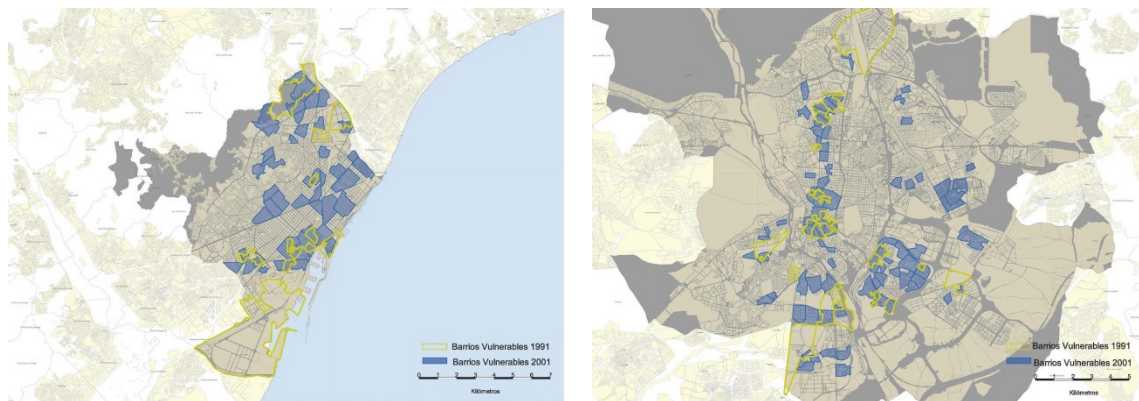


Figure 1 Map of neighbourhoods that were defined as vulnerable according to census of 1991 and 2001 in the cities of Barcelona and Madrid. Neighbourhoods that are shaded in blue, were included in the catalogue which was carried out in 2011 (from 2001 census data) and those represented in yellow line were delimited in 1996 (according to the 1991 census data).

As shown in figure 1, many of the neighbourhoods that were defined as vulnerable according to data from 1991 census, remained the same regarding 2001 data. Overall, social and urban segregation processes were found to be constant overtime in some areas among these neighbourhoods. Many of them are *historic district*, *public developments from 1975 to 1990* or *peripheral allotment areas*. These neighbourhoods, in which networks facilities and equipments are weaker, access to green areas is more difficult, are unstructured neighborhoods and have little relevance as a functional part of the city. Rehabilitation plans or programmes have been carried out in many of them and have been relatively successful in terms of improving part of the housing stock, but have not resulted in a comprehensive and sustainable improvement (urban, social, economic and environmental), which have resulted in a perpetuation of the socioeconomic problems.

Moreover many of the neighbourhoods that were defined as vulnerable, according to the 2001 census data, were not vulnerable according to data from 1991. In the light of these results, a new group of neighbourhoods with different degrees of vulnerability were found. There are neighborhoods that may not necessarily be described as excluded neighborhoods, but in contrast may be located in a weak position compared to the rest of the city. Given these processes, new problems related to the lack of access to basic goods and services arose, what makes urgent the definition of other models of intervention for the urban reality.



The aim of this paper is to pose a reflection on the *urban support* as the key to ensure access and the right to the city of that population more in need regarding the urban vulnerability processes that take place in our cities.

The interest of this discussion lies in the possibility of developing comprehensive intervention models for the existing city which may be able to adapt them to changing needs. This involves a greater involvement of subjects in determining the urban structure as a satisfactor element for their own needs; it *“is about reconstructing the concept of need for sustainability, not only from the relative lack”* (4).

### **Vulnerability and assets. The urban support as a generator of capabilities**

The concept of vulnerability can be understood from different points of view. The sociologists Alguacil and Camacho understand the concept as a process of discomfort caused by the combination of multiple dimensions of disadvantage (social, economic, urban, etc), *in which all hope for an upward social mobility, determined to overcome social exclusion condition or close to it, is regarded as extremely unattainable* (5).

The term has been frequently used as a synonymous to poverty, but it is not the same. Poverty is usually associated to a particular time; it is essentially a static concept, while vulnerability is a more dynamic concept and allows the definition of processes. From the urban point of view it means that the poorest and excluded neighborhoods are undoubtedly the most vulnerable but, in contrast, not all poor neighborhoods are vulnerable.

From a socioeconomic point of view, each neighborhood has some capabilities that make it more or less strong or resilient against adverse circumstances. They may count on capabilities that deal with economic, social or educational qualities of individuals, households or groups. But beyond their capabilities, each neighborhood must have other means of resistance, namely *assets* and rights that individuals, families and communities can mobilize and manage to face difficulties. The more assets they count on, the lower vulnerability may be. The more wear they have, the greater the insecurity is towards a downward mobility process. The assets are generally measured in relation to household (disposable income, real estate, etc.). Socioeconomic variables are used to define the position of individuals, neighborhoods or towns within the segmentation axes Wealth - Poverty / Inclusion – Exclusion, in which several positions or zones can be found (see figure 2).

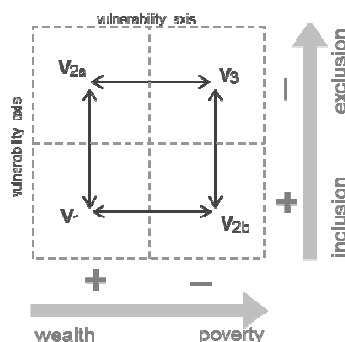


Figure 2. Vulnerability zones through segmentation axis.

In addition to social (human capital, education, etc.) or economic assets (access to the labor market, economic, etc...) and transferring the concept of *asset* to an urban planning



perspective, we understand that an individual, a district or a city has other elements that can work as *urban assets* and that will influence the position of each of them in the segmentation axis of vulnerability. We refer to all the elements that constitute and structure the city, empowering each area or district to meet their own needs. These elements are considered as '*indirect social wage*' (4) which we define as *urban support*.

On one side, the *urban support* would refer to those requirements that are determined by planning, regarding the size and the variety of amenities and facilities so as to avoid the loss of functional coverage. These are all those elements that define the built environment and ensure the potential accessibility, which is understood as the opportunity for people to access goods, services or products. These requirements would be given by urban standards, physical structure, density, size, distances, etc; in essence all those elements that enable to define the area as a structured neighborhood. All of them make up the built environment and therefore would be required as satisfiers of needs identified in quantitative terms. However, they are not enough if we pretend the reconstruction of the concept of need in terms of social, environmental and economic sustainability.

Thus, the concept of *urban support* must be understood as a complex system where, apart from the built environment (facilities, housing, squares, infrastructures, parks, etc), there are also interrelated social spaces which shape a set of spaces that serve as social and cultural support to which everyone should have access. This aspect of *urban support* is the key to understand that ensuring a potential accessibility does not ensure the total accessibility of people to their environment, just because the urban space is not guaranteed as a satisfier of needs inherent to Human Scale Development (6). In this theory, human needs are defined as an unitary system in which they relate and interact. Thus, they are considered as "*the sum of existential needs (be, have, do and be) and axiological needs (subsistence, protection, affection, understanding, participation, leisure, creation, identity, freedom)*".

### **Accessibility and the urban support**

Access to the city in all its complexity is a perennial and a recurring theme in urban research, either if it is from a social, economic, anthropological or purely urban and territorial perspective. In every period and according to each discipline, approaches change depending on the problems they have to cope with.

In order to ensure access to the city on equal terms, it must be taken into account the different types of open spaces and its uses, the variety and complexity of the requirements and the different urban scales (housing, neighbourhood, district and city) regarding possible border or boundary spaces between the different scales. The relationship of each neighbourhood within the city must be present. For that purpose, the elements that define the neighbourhood *urban support*, should contribute to avoid exclusion processes through the incorporation of each area or neighborhood as a structural element of the city and therefore necessary for the rest of it (see figure 3).

All these spaces built or not, constitute the urban support that is intended to endow citizens, regardless of their physical, social, economic or cultural characteristics, with social benefits or collective services. These spaces also define the quality of the urban model in relation to the system of public spaces and facilities that were developed to serve the city.

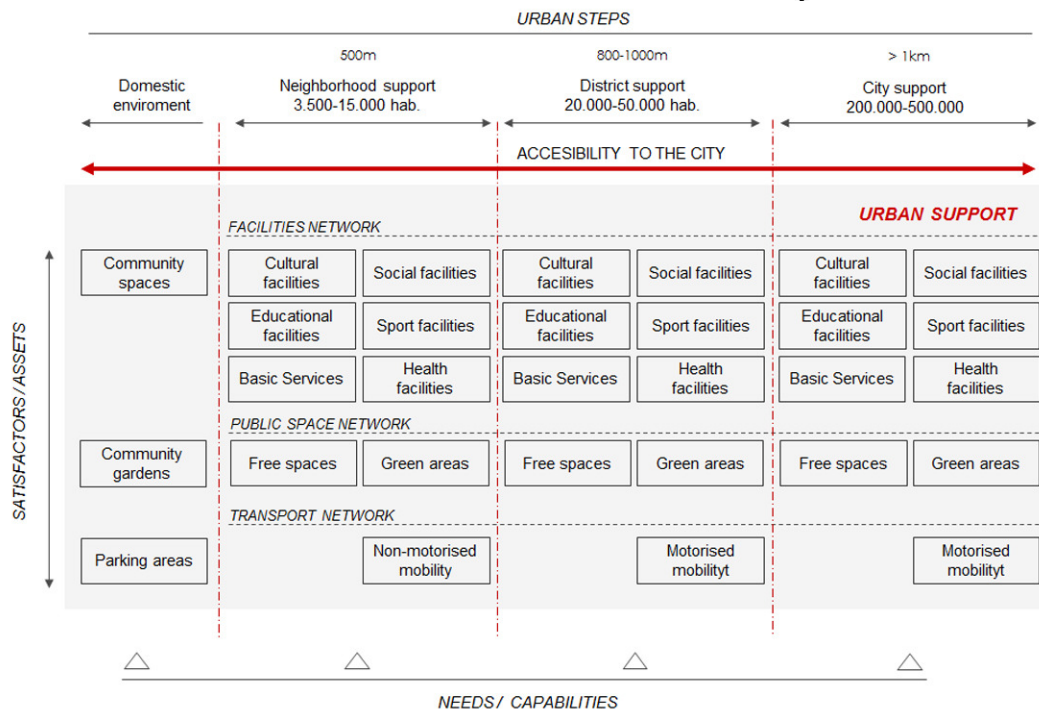


Figure 3 Conceptual schemes that explain the relationship between accessibility and urban support in order to ensure structured and structural environment

Accessibility shortfalls in the city imply lack of access to goods and services offered by the city in all areas and diminish the quality of the urban environment and people's welfare. It also reduces the possibility of integration in the built environment and even damages the environmental quality of cities. Rethinking the city through the concepts of *accessibility* and *urban support* allows us to reconstruct the functional nature of the urban environment so as to ensure quality of life by reducing the urban and social vulnerability.

### Urban Support in the context of the comprehensive regeneration of neighbourhoods

As a result, it is interesting to develop a deep insight into the way precarisation of the urban support affects the processes of vulnerability, in order to develop appropriate indicators.

Among the 624 neighbourhoods that were catalogued as vulnerable (3), a variety of problems and situations, both socioeconomic and urban, can be found. However, considering the results, certain patterns or similarities can be built and thus, it is possible to define the different levels of resilience of neighbourhoods in relation to their socio-economic vulnerability. All this can be established taking into account the assets and capabilities of each neighbourhood and their urban vulnerability which can be measured through the analysis of total and potential accessibility to the urban support.

Derived from the results of the urban vulnerability analysis in Spain, it can be stated that indicators which measure the level of education or access to the labour market were



benchmarks for detecting situations of exclusion or disintegration. The 40% of delimited neighbourhoods exceeded 1.5 times the national value in relation to educational level and the unemployment rate, and the 60% of the neighbourhoods had a ratio of temporary workers above the 30%. Given these socio-economic data along with the location of these neighbourhoods in the city (which are generally located in periphery areas), it can be ensured that access to the labour market, which means access to urban support that structures productive uses, remains a key part of the process of urban vulnerability.

However, it is detected that more than 50% of the 2001 delimited neighbourhoods, exceeded a rate of 40% of dependency. Most of them are aging neighbourhoods (more than the 50% of them have a 10% or more of over-65-year-old-single-person households) with their particular needs and strong gaps in access to urban support in its different scales. In these cases neighbourhoods with a relative or moderate vulnerability were found. In these cases, socio-economic aspects did not define a pattern of exclusion but, there is a risk of social decline or vulnerability increase during an economic crisis like the current one. These neighbourhoods become more likely to generate strong problems related to relative poverty and also related to their integration in the city.

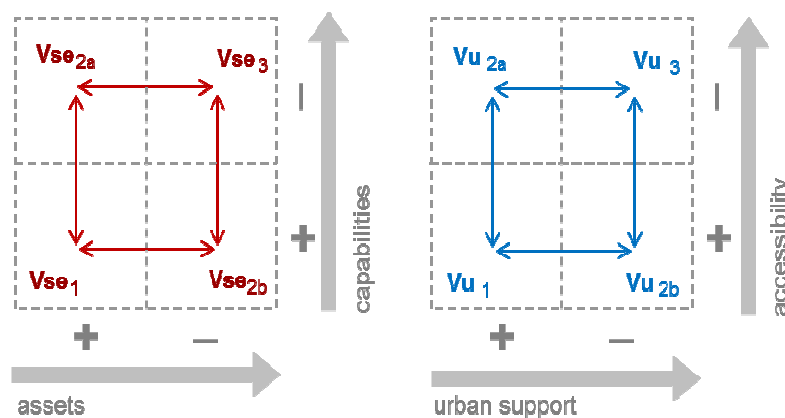


Figure 4. Socio-economic and urban vulnerability zones through segmentation axis.

In this regard, it is important to characterize the different processes of vulnerability from a multidimensional perspective including both socioeconomic and urban variables that can be adapted to each neighbourhood problems serving both the degree and the type of vulnerability. For this characterization, the use of the concepts described above is proposed by relating them in position tables (see figure 4).

The first position table seeks to characterize the vulnerability in relation to the capabilities and needs of the population in order to identify major gaps or asset levels as an element of resistance to brittleness. Thus, four positions of socioeconomic vulnerability (Vse) are distinguished through the ratio of assets-capabilities. The more assets and capabilities they



count on, the lower the social vulnerability is. Similarly, in the second table four positions are also defined in order to characterize the urban vulnerability (Vu) in relation to the binomial accessibility- urban support. The better the urban support and accessibility are, the less urban vulnerability exists.

Both tables are linked in order to understand in a more complex way the processes that can result into different levels and types of vulnerability.

This method of analysis can produce useful and complex appraising so as to develop comprehensive strategies aimed at improving neighbourhoods. It is intended to keep track of a basic objective to be pursued any urban intervention, which would be to build an integrated and well-adjusted city. It is not possible to improve a vulnerable neighbourhood dismissing its contextual either social or urban situation. The urgent need of creating structured neighbourhoods with their autonomy and training must be understood along with a recognizable structure in its urban and metropolitan context.

## References

- (1) Fernández Ramírez, C; Roch Peña, F (2012). La quiebra de la ciudad global y sus efectos en la morfología urbana. Madrid, bajo la lógica inmobiliaria de la acumulación-desposesión. *Urban: revista del Departamento de Urbanística y Ordenación del Territorio*, 2012, 03(06): 45-63, doi:10.3989/ic.11.058
- (2) *VI Informe sobre exclusión y desarrollo social en España (2008)*. Fundación Foessa, Cáritas Española, 2008.
- (3) Hernández Aja, A., Vázquez Espí, M., García Madruga, C., Matesanz Parellada, A., Moreno García, E., Alguacil Gómez, J., Camacho Gutiérrez, J.(2011). Análisis urbanístico de Barrios Vulnerables. Madrid, Spain. *Ciudades para un Futuro más Sostenible*. Available at: <http://habitat.aq.upm.es/bbv/bbv.html> (accessed 1.7.13)
- (4) Hernández Aja, A, et al (1997). *La ciudad de los ciudadanos*. Madrid . Ministerio de Obras Públicas Transportes y MedioAmbiente.
- (5) Alguacil Gómez, J; Camacho Gutiérrez, J; Hernández Aja, A (2013). La vulnerabilidad urbana en España. Identificación y evolución de los barrios vulnerables. *Empiria. Revista de metodología de Ciencias Sociales*, 27(28). 45-63, doi:10.3989/ic.11.058
- (6) Max-Neef, M; Elizalde, A; Hopenhayn, M (1991). *Human scale development: conception, application and further reflections*. New York. Apex Press.



## **A Project to Safeguard an Abandoned Heritage: The Revitalization of Golea (Algeria)**

Dr. Madani, S; Diafat, A.  
Laboratoire PUViT, Université Sétif 1, Sétif, Algeria,

**Abstract:** *This paper presents a promising experience of revitalizing the historic village of Golea in Algeria. This village witnesses continuous deterioration and a social shift due to the migration of its local population.*

*The objectives of this project were to develop a comprehensive approach and implementation strategy that would lead to the economic and social revitalization and insuring a sustainable cultural development through the maintenance of the city components. The role of heritage and mountain tourism, their implications for urban conservation and heritage, as an essential element of sustainable development, will be discussed.*

*The methodology approach is based on a thorough analysis of the process concerning this collective product. There will be an investigation through the different steps from the project definition to its design.*

*This project for Golea as a source of lessons for contemporary architectural design is calling other similar projects claimed by the local community.*

**Keywords:** *Heritage, Golea Project, Community, Strategies, Design.*

### **Introduction**

This paper presents a promising experience of revitalizing the historic village of Golea in Algeria. This wonderful village witnesses continuous deterioration and a social shift due to the migration of its local population. In fact, Golea is facing a problem of depopulation; this heritage is deserted during the "black decay" in the Nineties due to the insecurity and the lack of basic needs necessary for everyday life, so that the villagers fled from the mountain to the lowlands. The concern of the local authorities seeking for an innovative solution for this historic heritage resulted in the project of revitalization.

The Golea project aims to restore some ancient customs based on faith and "self-reliance" and that led to the heritage in general and those of Kabylia especially to survive in a mountainous environment worthy of the sustainable development. This project is designed to contribute socially, economically, physically and aesthetically to regenerate the local urban environment and empowering the community ties.



## **Theoretical Framework**

Urban conservation (preserving tradition, social and cultural aspects as well as the physical improvement of historic buildings) is often witnessed as an approach towards higher levels of sustainability. Concerning preservation and conservation of old monuments of historic value the international organizations are achieving great success. However, this often excludes historic residential areas and historic city centers which equally are representing the urban heritage. In addition, there are other cultural non-tangible elements of urban heritage such as: customs and beliefs. These non-tangible elements play a key role for the articulation of complex space use and the built environment. (1)

In historic districts, the development projects tend to attract a variety of economic activity and competition, therefore encouraging both new inhabitants and visitors to revisit and rediscover these restored vicinities. Moreover, upgrading the physical built environment, social fabric and urban spaces within the historical urban structure all contribute towards increasing their acceptance as public places for different activities. This consequently increases social interaction and cohesion between citizens. Furthermore, conservation and regeneration of historic sites most evidently located at city centers tend to re-affirm residents' feelings of identity and sense of belonging. (2)

The heritage is a factor of social stability as a sign of recognition and belonging to a territory. But heritage is not a dead object; it is marked by community ties, rich in meaning and usage, it is alive and holds an emotional charge that does not necessarily contain references or architectural aesthetics. The objective to value the heritage reveals the importance of respecting the cultures and the human activities that reflect the past and present values through the use and activities of a society. (3)

The economic implication of heritage is a challenge to create wealth, provide resources and generate added value for the social economy. The heritage could contribute to the socio-economic dynamics of the country by providing jobs, promoting income and reduce poverty. To involve successfully the Heritage in the dynamics of the sustainable development and the fight against poverty by focusing on two areas: tourism and the restoration - conservation industry. (4)

## **Methodology**

The methodology approach is based on a thorough analysis of the process concerning this collective urban and architectural product. There will be an investigation through the different steps from the project definition to its design.

A team composed of three teachers of architectural studio and three students of fifth year architecture, in addition to the civil society in Golea were gathered for the project with the local Authorities assistance. A period of preliminary research, studies and design lasted from September 2012 till July 2013.



The team's proposals covered the following topics: legal framework, economic aspects as well as income generation, conservation areas, urban design and architectural issues, restoration, field surveys, social empowerment.

## Project Context

Historic villages that need to be protected and enhanced begin to disappear gradually, there is a depopulation phenomenon. Due to the lack of primary needs and management, the villagers leave behind them the land of their ancestors and their heritage in all its forms; they prefer living in the valleys and cities.

Kabylia is a hilly region, where these villages are built and concentrated in a circle or lying on the peaks of mountains or peaks nipples separating valleys, with physical structures reflecting a conceptual image of the world and life based on beliefs and sociological values (see Figure 1 and 2). Inside the village there are several dead ends which open outwards by two or three streets. The villages are designed in a defensive manner, turning back outside, while opening on narrow paths. Their boundaries are well defined. Each village is composed of several units called Adroum, and it is a group of people who all have ties of kinship and descent.

Some Berber villages still exist and with a large number of people, others have disappeared over time for many reasons, including economic.



*Figure 1: The Golea site in 2013*  
Source: the authors, 2013.



*Figure 2: The Golea site in the sixties*  
Source: the archives of the Golea civil society

## Heritage of Golea

Originally a center of worship and piety described as a small citadel. The history of the village seems to be mixed with this built entity for nearly six centuries. Golea which means in Arabic: small citadel, it is probably the Mount's name above which was rebuilt repeatedly the current mosque which is accessible only by the single lane alley designed as a rising street.

Before this designation is extended to the whole village and its region, the collective memory retains that around the fifteenth century, a Syrian-born worship man, namely Ahmed Abu Homs has chosen to establish precisely on the Mount.





The village has seen good times and sometimes serious crises with at least three periods of desertification around the middle of the last century. There were drought and starvation during the last years of the French colonization and the recent phenomenon accentuated by the "black decade" (1990-2000)

Golea was chosen as a case study regarding its specificity and, to a certain extent, because of the importance of the problems it raises:

- Difficult accessibility to the village, which looks very isolated.
- The activity of exchange and production of traditional type (carpets, oil, olives ....)
- The main characteristics of its historical heritage were intact and are vital reference points.

From a planning point of view, the main factor would be to reconsider the role of the village, due to the specificity of its fabric. But since it is the prime location of certain activities, it is necessary that intervention in the village reinforces these core functions, it provides the integration of economic activities and tourism facilities compatible with the characteristics of the historic village.

### **Project Principles and References**

The cultural and natural context of Golea with its architectural appearance and cultural value could be one of the factors causing a sustained process of rehabilitation and upgrading of housing and urban fabric. So the preservation of this heritage, the restoration of houses, coupled with a policy of revalorization of the mosque and public spaces in the village can create favorable conditions for further development of activities.

This approach therefore focuses on the rediscovery of the potential of an urban structure with architectural and urban features that can be recovered through interventions in the short and medium terms. From this perspective, special attention was dedicated to certain elements that are fundamental to the organization of the historical fabric of the village: mosque, a small square at the entrance of the village, hill reservoir, Eldjmaa (public space), fountain and houses. (see Figure 3)

The first research step concerns the potential of these structures, purposes and forms that could be reused. The houses with their historical and architectural character must be saved and rehabilitated as part of the upgrading community life. We also studied some structural elements of the historic urban fabric, such as the fountain, the public space El djmaa which functions are now severely deteriorating.

The houses mark the residential fabric of different neighborhoods around the mosque, these buildings need to be rehabilitated, reclassified, revised as houses and allocated with cultural function. The shops in the central part of the village, around the public space (Eldjmaa), are decaying buildings. The intervention for the rehabilitation of this habitat provides an opportunity to convert these structures for commercial and craft activities and open them to the public. There is a progressive and widespread deterioration of housing and urban environment, deficiency in infrastructure and services weakens economic activities.

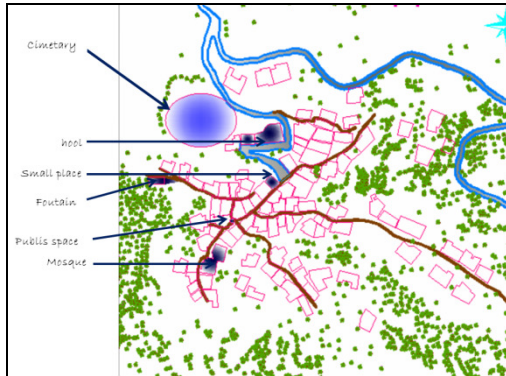


Figure 3: The Golea Elements of permanence  
Source: the authors, 2013.



Figure 4: The Golea site in 2013  
Source: the authors, 2013.

### Program of the Project

It is possible to achieve a balance between tourism development, conservation and heritage preservation through the implementation of comprehensive rehabilitation policies that take account not only of the building or site heritage, but also of the natural and urban environment in which it is inserted and respect the lifestyle of its people, their culture, their identity and traditions (see figure 4). Investment activities that can be implemented in the architectural heritage and act in the built heritage sites are classified into two main groups.

The first group of activities that can be implemented within the architectural heritage:

- Housing: restore large houses that are inhabited to welcome tourists in rooms specially reserved to them, which will allow mutuality and a cultural sharing in the context of tourism solidarity. This will allow the inhabitants to consider their responsibilities towards their land, their customs and traditions and share them with others. (see Figure 5)
- Museums for exhibition the popular heritage.
- Restaurants (local food). (see Figure 6)
- The Mosque. (see Figure 7 and 8)
- Arts and Crafts House: this house is a place for exhibition, learning and sharing. It will be equipped with small shops selling handicrafts objects, with the integration of several activities that transmit local culture.
- Other activities: a large number of various activities such as reception and information center, reading rooms, open or closed theater for performances and religious, cultural, and scientific conferences.

The second group of activities that can be implemented in the surrounding area of the architectural heritage:

- Sites for folk practice.
- Ways for cultural activities, sports and some public services, other entertainment programs compatible with local traditions.
- A park and greenery: With a water source, a cafeteria and a restaurant representative of the local gastronomy.
- Commercial and leisure activities.



*Figure 5: The hostel project*  
Source: the authors, 2013.



*Figure 6: The restaurant project*  
Source: the authors, 2013.



*Figure 7: The Existing mosque*  
Source: the authors, 2013.



*Figure 8: The mosque project*  
Source: the authors, 2013.

The objective of this urban project is the sustainable development. The project's approach is the interpreting and reading the old city through its past in an operational goal. This sustainable development approach is taking into consideration the cultural and symbolic aspects of the city; it is not limited only to the technical aspects.

### **Place and Role of the Villagers**

The place and role of the villagers in the process to safeguard and revitalize this abandoned heritage must be defined or at least performed and associate them for the assessment, it is a political issue. Therefore we consider the most appropriate ways to encourage the presence of people directly involved in this urban project.

To facilitate the expression of the people, several methods were suggested such as surveys conducted by students, specific animated roundtables, the time devoted to evaluation in neighborhood councils or urban animation workshops for exchange between villagers, members of the technical committee (project manager and technicians) and local authorities.

Involving all partners in the process is necessary. This mobilization must be coordinated and carried politically. In this respect, the approach must deal with several challenges:

- Mobilize partners around a prospective vision of the Golea future;





- Bring together partners who were never involved before;
- Maintain an effective organization while designing the project to safeguard this abandoned heritage within a reasonable time and avoid dilution of the process.

The involvement of residents and users, through specific working groups greatly enhanced the work of diagnosis and identification of priority issues of revitalizing the historic village of Golea. An executive committee: this will make people aware and understand the value of their land and their heritage through seminars and symposia that will manage and continue the perpetual development in the touristic village. But it will also manage the organization of the village and ensure it meets the needs of residents and visitors.

## Conclusion

The strengths of this promising project to safeguard and revitalize this abandoned heritage could be summarized as follows:

- Integrate the current economic environment.
- Enhance social cohesion and traditional customs; the programming of collective activities for the site will help creating a social environment that exists in Golea.
- Conciliate practices and values of cohesion and social aid with the demands of contemporary comfort. The design is responding to the mountain environment by bioclimatic comfort; the proposed elements creating a bioclimatic micro environment with shading circulation paths, protection against wind, green space.
- Attempt to improve the status of the traditional Berber habitat;
- The housing preservation is responding to the inhabitants' needs, it is based on the traditional urban and architectural heritage.

In the Golea project, the self-reliance and the Touiza "voluntary", both ancestral values of the Berber region, associated with the local authority's participation could surely help to realize the project. The user's participation in the creation of their home environment is the best incentive for them to preserve it and give it a long life. Living the process of your own dwelling birth makes it a part of your memory and sustainability follows. Tourists have started again to visit Golea village and that contributes to its socio-economic dynamics.

## References:

- 1- Hampikian, N., (1999), Challenges Facing Conservation Projects in Historical Cairo. *The 9<sup>th</sup> Conference of Union of Egyptian Architects. Architectural Heritage and Urban Development*, Cairo-Egypt.
- 2- Elnokaly, A. and Elseragy, A. (2013). Sustainable Heritage Development: Learning from Urban Conservation of Heritage Projects in Non Western Contexts *European Journal of Sustainable Development*, 2, 31- 54.
- 3- Rouxel, F. (1999). *L'héritage urbain et la ville de demain. Pour une approche de développement durable*, METL.
- 4- Benyoucef, B. (2007) *Le patrimoine à l'ère de la globalisation : enjeux, défis et Perspectives*. Colloque international: La vallée du M'Zab, patrimoine mondial, face aux nouveaux enjeux et défis, Ghardaïa, 10 - 12 décembre 2007.



## **RESSÒ: energy efficiency urban rehabilitation**

### **Authors:**

Bodelon, Carmen<sup>1</sup>; Gascón, Eduardo<sup>1</sup>; Ramon, Guillem<sup>1</sup>; Obiols, Martí<sup>1</sup>; Palomar, Pablo<sup>1</sup>; Escoda, Quim<sup>1</sup>; Prat, Sandra<sup>1</sup>; Illa, Sergi<sup>1</sup>; Nadales, Víctor<sup>1</sup>; Callejas, Xavi<sup>1</sup>

<sup>1</sup> RESSÒ-UPC-ETSAV, Sant Cugat del Vallès, CATALONIA

**Abstract:** *Ressò is an urban regeneration strategy that reinterprets the current lifestyle. Collectivization is our tool to optimize resources and improve users' comfort. Ressò triggers a process in the local community that implies a new management of resources. Using this community space throughout years will bring economical savings that could be invested in an energetic improvement of the private space.*

**Urban rehabilitation, energy efficiency, collectivization of uses, resources management**

### **URBAN CONTEXT AND STRATEGY**

The social, economic and environmental crisis in which Spain is immersed lead us to an unsustainable and complex situation that made us rethink about our way of life. In front of a large inefficient building stock and new housing with no demand, it makes no sense to keep building more, instead we must think how to improve the existent one.

A big-scale rehabilitation plan is not only necessary, but also affordable. Unfortunately, it seems that nowadays is not working at all, mainly due to a lack of interest of the Government and institutions. However, early or late, we will be forced to do it because of the environmental pressure (20/20/20 objectives) and the cost of the energy.

By the other side, we can not just keep complaining about the situation while is getting worse: the unemployment rate is up to 26%, and the energy price, the evicted families (30,000 just in 2013) and the fuel poverty (around 15%) are increasing alarmingly. We must act as soon as possible and we firmly stand that the key in this rehabilitation is the people. The solutions might arrive through the collectivization and the pedagogy.

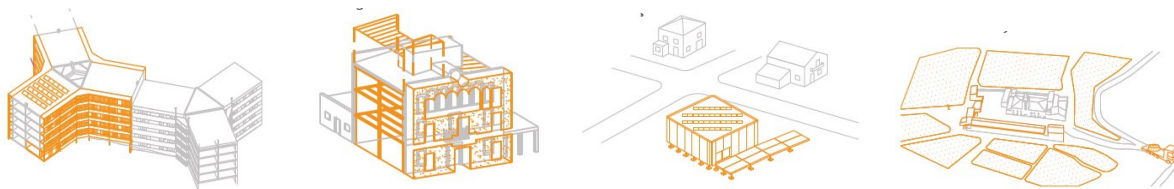
In time of crisis, when the usual models do not work, we must rethink and propose non-conventional solutions in order to change the situation. As a future professionals compromised with the society, we should impulse an energetic rehabilitation promoting the social cohesion, granting the comfort of the vulnerable people and spreading the awareness about the importance of the resources. The way to do it is working on the user behaviour, that is as important as to the intervention on the buildings.



In that way, we define Ressò as an urban temporary strategy, that reinterprets the way of life and its objective is to solve the social and energetic weaknesses of a specific urban context.

This strategy is a working method applicable to different urban fabrics and would be materialized according to the complexity of every context. However, is just a theoretical strategy that we need to test and is indispensable to implement it in a real urban context.

Consequently, we analysed different urban fabrics in our close surroundings that could be indicated places to implement the strategy. Beside they are quite different, they have common characteristics like low efficiency buildings or people with difficulty to pay their energy. These places are Badia del vallès (high density), Sant Cugat (medium density), Sant Muç (low density) and Can Montmany (super-low density)



*Diferents urban fabric proposals: Badia, Sant Cugat, Sant Muc and Can Monmany*

## REAL URBAN CONTEXT

In this case, we have chosen the low density suburb of Sant Muç to make real our strategy. The rehabilitation in low density is an interesting challenge for us due to is a difficult fabric to rehabilitate and most people in Europe live on a single-family dwelling. Moreover, Sant Muç is characterized by our target: high energy inefficiency housing and medium-low rent population, that many times is fuel poverty risk. On the other hand, the important lack of services force their inhabitants to move by car to the city of Rubí, which it is located 4 km away.

The strategy in Sant Muç consists in a network of 5 collective houses. These “Ressò houses” will satisfy the needs that people could not satisfy in their homes allowing domestic and social activities, both collectively. Thus, Ressò will strengthen the social relations, allow energetic and economic savings by reducing consumptions and will be a shelter for vulnerable people.

However, the most important is the function of the house as a “teaching tool”. The neighbours will satisfy their needs in a zero energy house, and through the experience they will learn about a new way of living responsible with the environment. Once they experienced the low-energy systems of the house, they would be interested in apply the rehabilitation in their homes in a next future.



## **RESSÒ's EMBODIMENT**

Ressò space's materialization will depend on the reality of every single urban fabric where it is implemented and should be adapted to every particular case depending on the needs, resources and opportunities found there. However, Ressò always follows a material strategy based on the use of as less resources while accomplishing as much requirements as possible.

According to this, we base the materialization on the balance between the following concepts:

- Availability: real access to human resources and materials.
- Affordability: in relation with time (assembly, transport, machinery...) and cost (sponsorships, institutional support, materials, manpower...)
- Effectiveness: in accordance with the performance and accuracy to its aim which basically are functional, adaptation to the context and ecological requirements.

Thus, we pursue equilibrium between a good functioning of the building, its economic cost and materials and humans resources needed to carry it out.

Proposal's basis remains in the potential social synergy of collectivization- both in urban and in energetic needs. Ressò space may accomplish with some requirements:

- The size will be defined as a balance between number of users, maximum surface (determined by the urban context) and an appropriate height.
- The space has to be flexible and adaptable in relation to the needs of its use, allowing it to be either a single space to develop a single activity or multiple spaces for several activities. The adaptability of the space goes hand in hand with the users conditions.
- It has to offer affordable comfort (affordable warmth),-by which we do mean it has to be provided at no cost to the users. It can be achieved if the space is self-sufficient; - energetically speaking- thus the space is disconnected from the main electricity supply. So it has to be able to generate all its demanding energy.
- It may be self-buildable by which we do mean users have to comprehend how systems are applied in this space work. They may arrive to get basic knowledge of these systems that may allow to apply them to upgrade their own homes.
- Both low technical and suitable-to-build solutions should be prioritized in order to reduce the use of machinery. There are two key reasons for this; Firstly, the comprehension of basic concepts of daily functioning of the home, secondly the

awareness of the users. Make them understand that they may improve the habitability of their homes taking an active part in its performance.

- Promoting the change from a passive user to an active user, conscious of both the importance of resources and a more responsible way of living according to the current situation.

Ressò triggers both a process in the local community that implies a new management of resources (water, energy, food, mobility and waste) and a space which may meet urban fabric needs. The fact of collectivizing may be a strategy to generate new programs and activities which may arrive to supply new future realities.



*Ressò prototype interior view*

## **RESSÒ's ENERGY STRATEGY**

Occupancy and activities in Ressò space can be so many and so different that we can not understand comfort as a fixed number. For that reason, we use comfort as a much wider range that depends on many factors (relative humidity, radiant T, occupancy...) and that is adaptable to the different situations.

Also, we must understand the prototype on its second live as a place where the society awareness of a correct and efficient use of energy and resources is basic (energy culture). To achieve this, we suggest the prototype's energetic self-sufficiency as a didactic method. In this way, the building will offer affordable warmth as many days as possible, making use of low technified climatic systems that allow the user get to know bioclimatical architecture concepts they could apply to their own homes.

The main passive strategies of Ressò space are:

### **- PROTOTYPE'S ENVELOPE**

Ressò's envelope has a bioclimatic design formed basically by:

- a) Three insulated faces in order to minimize energetic losses where the building exchanges more energy with the exterior: the roof and façades oriented to north-west and north-east respectively.



- b) One face with thermal mass in order to provide inertia to the building. This allows the prototype to flatten its temperatures and to depend less of the exterior conditions.
- c) Two faces oriented to south-east and south-west in order to follow the sun path and therefore manage the radiation that arrives to the building throughout the day.

#### - FLOOR'S THERMAL INERTIA

Ressò's soil embodiment made as a huge mass which absorbs energy and releases it later to balance the interior temperature when needed. In summer, during the day it absorbs the excess of heat in the prototype and at night, ventilation is forced so the floor is able to dissipate all the accumulated energy. In winter, it receives direct solar radiation and stores energy in order to condition the space passively.

#### - DOUBLE SKIN FAÇADE

It manages the radiation that arrives to the prototype and has three basic positions:

- a) Summer: using a screen inside the double skin we avoid radiation entering the prototype. Also, due to the temperature and pressure differences between the upper and lower part of the façade inside chamber, solar chimney effect occurs in order to evacuate the overheated air not only from the double skin, but from the interior space too.
- b) Winter day: let the radiation come inside in order to heat the floor. Also, the hot air inside the chamber is recirculated inside the prototype by opening the inner skin windows.
- c) Winter night: the double skin works as thermal buffer, improving the façade's U value.

#### - VENTILATION

Ventilation strategy is mainly based in the crossed and night ventilation of the space. The last one helps inertia to start in the morning at a lower temperature to absorb more heat during the day. Both

#### - PARTITIONING

The prototype must be able to adapt to different occupation situations. Therefore it is necessary to have a system of partitioning the space which is easy to mantle and dismantle and that increases the efficiency of the underfloor heating by reducing the volume.

## - AIR RENOVATIONS

4 of the double-skin panels are specialised on air renovations and air quality. Inside them, plasterboard is accumulated in order to maintain hot air inside the façade chamber. A vent in the upper part puts hot and clean air inside the prototype and therefore minimizes energy losses during air renovations.

Our prototype is a machine but plugged to the environment, as it achieves comfort basically through these passive systems. But we do assume that depending on the weather and internal conditions the prototype might be beyond comfort ranges during some periods of time. To maintain comfort also in those moments, we use active systems.

Our only HVAC system is the underfloor heating and its objective is, by circulating hot or cold water, to strengthen what the floor's inertia achieves in a passive way: to flatten the interior temperatures. It is a system that influences very positively in the user's comfort as it modifies the operative temperature of the space. This means that it not only changes the air temperature, but also the radiant temperature of a surface that is in constant and direct contact with people.

The system consists of 10 panels of 2x5 m. each, and it is possible to activate all of them or only some (as in the case of the SDE competition). The temperature of the supplied water is the same for all the pieces (40 °C) and the way of controlling the power of each panel of the floor is regulating the water flow. Hot water is obtained from vacuum tubes and cold water from a dissipation system under the prototype.

Using Design Builder and similar tools we searched for an optimal design of the floor. First, regarding the final position of all its components (distance between the water pipes and the inner surface, total thickness of the floor...) and then regarding the usage schedules.

## CONCLUSION

Ressò's final aim is to "speed up" the individual rehabilitation process through the pedagogic task done by the prototype. The individual rehabilitation will be financed through a low-interest credit supported by the Government and that would be returned with the future individual



*Ressò prototype exterior view*





house savings in energy costs and a little amount of money saved thanks to Ressò. For those who can not pay their comfort, they will not be able to upgrade their home or they will do it at a very long term. In these cases their comfort will be granted by using more often the Ressò house.

## Field Survey on Physical Activity Affected by Housing and Community

### Speakers:

Yanagisawa, Megumi<sup>1</sup>; Toshiharu, Ikaga<sup>2</sup>; Shintaro, Ando<sup>3</sup>;

<sup>1</sup> Keio University, Yokohama, Japan

<sup>2</sup> Keio University, Yokohama, Japan

<sup>3</sup> Keio University, Yokohama, Japan

**Abstract:** *In recent years in Japan, promotion of physical activity has been emphasized as a means of preventing lifestyle-related diseases. Accordingly, we aimed to elucidate factors associated with physical activity, particularly among the elderly. We conducted a questionnaire survey and actual measurements to examine how housing and community environment are related to physical activity. Statistical analysis of the data yielded the following main results. First, indoor and outdoor sound and vibration in the living room were found to be correlated with physical activity. Second, participation in community or neighborhood activities, usability of meeting facilities and libraries, aesthetic aspects of townscape and view, and high-density housing were found to be positively associated with physical activity. Third, factors pertaining to the indoor thermal environment, namely, a high mean/minimum temperature of the lavatory and a small temperature differences between the living room and other rooms, were found to be positively associated with physical activity.*

**Keywords:** *Health Promotion, Physical Activity, Indoor Thermal Environment, Field Survey*

### 1. Introduction

In recent years in Japan, promotion of physical activity has been emphasized as a means of preventing lifestyle-related diseases [1]. A great deal of research has been conducted on environmental factors that influence physical activity, but much of that work deals with only the community environment and so the relation between housing environment and physical activity remains unclear. Against this background, we aimed to clarify the effects of housing and community environment on physical activity.

### 2. Summary of the field survey

This research was conducted as a field study comprising a questionnaire survey and actual measurements. The study area was Niihama City in Ehime Prefecture, Japan. The measurements were conducted during winter. Using the survey results, we performed statistical analysis to examine the relations of housing and community environment with physical activity. With respect to the thermal environment, we hypothesized that inhabitants would be hesitant to perform physical activities in cold houses during winter and that the amount of physical activity would therefore decrease. To test this hypothesis, we examined the relation between indoor thermal environment and physical activity.

#### 2.1. Questionnaire survey

As shown in Tables 1 and 2, the questionnaire evaluated the housing and community environment [2][3], the degree of physical activity [4], lifestyle, and personal attributes. In regard

*Table 1 Overview of questionnaire survey*

Targets	Adults residing in Niihama City, Ehime Prefecture, Japan
Survey period	August 25 to September 10, 2013
Number distributed	3,838 households (2 copies per household)
Number returned (rate)	2,090 households (54.5%) 3,272 subjects
Distribution and collection	Distribution and collection by local community associations

*Table 2 Questionnaire survey content*

Part 1: Community environment			
I. Removal of function-disabling factors		II. Sufficiency of encouraging factors for activities and participation	
Natural environment <sup>a</sup>	Outdoor thermal environment (summer)	Participation in local activities <sup>b</sup>	Participation in community or neighborhood activities
	Outdoor thermal environment (winter)		Walking and sports
	Outdoor odor		Participation in cultural or lifetime activities
	Outdoor sound and vibration environment	Use of facilities and services <sup>b</sup>	Use of public transportation systems
	Outdoor air quality		Use of bicycles
	Green space environment		Use of exercise facilities
Safety and sanitation environment <sup>a</sup>	Aquatic environment	Practicality of facilities and services <sup>c</sup>	Use of meeting facilities and libraries
	Waterworks		Use of parks, public squares, and promenades
	Garbage dump		Usability of public transportation systems
	Smoking/non-smoking partition		Usability of exercise facilities
	Crowdedness or population density		Usability of meeting facilities and libraries
	Local safety (recognition of danger)		Availability of parks, public squares, and promenades
Traffic and Transportation <sup>a</sup>	Precautions against disasters	Health check-up facilities <sup>c</sup>	Accessibility of financial institutions
	Precautions against falling		Aesthetic aspects of townscape and view
	Traffic control		Accessibility and availability of medical clinics
	Accessibility of neighboring areas	Social capital <sup>c</sup>	Accessibility and availability of dental clinics
	Barrier-free		Communication and interaction with neighbors
	Fears of crime		Acquaintance with neighbors
			Confidence in neighbors
Part 2: Housing environment		Part 3: Physical activity (IPAQ)	
Attributes	Basic information	Vigorous physical activity	
	Insulation efficiency	Moderate physical activity	
	Usage of heating	Walking	
Living room <sup>a</sup>	Hotness in summer	Part 4: Lifestyle	
	Coldness in winter	Diet and eating habits	
	Indoor/outdoor sound and vibration	Smoking	
	Insufficient lighting at night	Drinking	
Bedroom <sup>a</sup>	Hotness in sleeping in summer	Clothing	
	Coldness during sleep in winter	Sleepwear	
	Use of air conditioner in summer	Dental care	
Kitchen <sup>a</sup>	Uncomfortable posture because of unsatisfactory layout	Time in home	
Bathroom, dressing room, and washroom <sup>a</sup>	Mold	Part 5: Health	
	Worry about tripping over a step	Self-rated health	
Corridors, stairs and storage <sup>a</sup>	Coldness in winter	Symptoms, illness	
	Stumbling over a step	Part 6: Personal attributes	
	Worry about steep stairs	Individual attributes	

IPAQ, International Physical Activity Questionnaire

<sup>a</sup> 0) Very often, 1) Often, 2) Seldom, 3) Never<sup>b</sup> 0) Never, 1) Seldom, 2) Occasionally, 3) Often, 4) Very often<sup>c</sup> 0) Very poor 1) Poor, 2), Good 3) Very good*Table 3 Overview of actual measurements*

Targets	Selected from questionnaire survey respondents
Survey period	January 10-23, 2014 (14 days)
Number of households	55
Number of valid samples (rate)	47 (85.5%)
Measurement content and instrument	Physical activity
	Daily step count, intensity of activity, etc.
	Measured by physical activity monitor (HJA-350IT Active style Pro, Omron)
	Indoor thermal environment
	Temperature and humidity of living room, bedroom, lavatory, and corridor
	Measured by thermo-hygrometer with data logger (RTR-503, TR-51i, T&D)



to housing and community environment, we asked about the frequency of dissatisfaction, the frequency of participation in activities, and practicality of the facilities and the services.

As shown in Tables 1 and 2, the questionnaire evaluated the housing and community environment [2][3], the degree of physical activity [4], lifestyle, and personal attributes. In regard to housing and community environment, we asked about the frequency of dissatisfaction, the frequency of participation in activities, and practicality of the facilities and the services.

## **2.2. Actual measurements**

We conducted actual measurements to assess the items in Table 3 pertaining to physical activity and indoor temperature. Physical activity was measured by using a physical activity monitor. Participants wore the activity monitors daily for approximately 2 weeks. The indoor temperature and humidity were measured with thermo-hygrometers installed at a height of about one meter in the living room, bedroom, and lavatory of each participant's house, and measurements were recorded every 10 min for approximately 1 month.

## **3. Impact of housing and community on physical activity**

### **3.1. Multiple logistic regression analysis**

We performed multiple logistic analysis to examine the impact of housing and community on physical activity after simultaneously controlling for individual attributes (Table 4). The dependent variable was the presence of vigorous physical activity and the independent variables were individual items subjectively assessing housing and community. Variables considered in the models were sex, age, length of residence, time at home, and usual mode of transportation. The analysis targets were 536 participants (Table 5) who were elderly ( $\geq 65$  years), who stayed at home for a long time, and who were not in regular employment.

### **3.2. Results of multiple logistic regression analysis**

The significant items are listed in Table 6.

With respect to housing environment, indoor and outdoor sound and vibration in the living room had a positive correlation with vigorous physical activity. This result indicates that inhabitants who are seldom bothered by indoor/outdoor sounds or vibrations often engage in vigorous physical activity.

As for community environment, participation in community or neighborhood activities had the strongest impact on vigorous physical activity. Moreover, among the items related to the practicality of facilities and services, usability of meeting facilities and libraries and aesthetic aspects of townscape and view had relatively high correlations. Because of the negative correlation between vigorous physical activity and crowdedness or population density, high-density housing is thought to be effective for promoting physical activity.

## **4. Impact of indoor thermal environment on physical activity**

### **4.1. Summary of multiple regression analysis**

We performed multiple regression analysis (stepwise selection) to examine the relation between indoor thermal environment and physical activity (Table 7). The dependent variable

Table 4 Overview of multiple logistic regression analysis

Dependent variable	Vigorous physical activity	0) None, 1) $\geq 1$ day per week
Independent variable	A Subjective assessment of housing and community	I. 0) Very often, 1) Often, 2) Seldom, 3) Never II. 0) Never 1) Seldom, 2) Occasionally, 3) Often, 4) Very often 0) Very poor, 1) Poor, 2) Good, 3) Very good
	B Sex <sup>a</sup>	1) Male, 2) Female
A: Input by one B: Input for adjustment	Age, years	1) 65-69, 2) 70-74, 3) 75-79, 4) 80-84, 5) 85-89, 6) $\geq 90$
	Length of residence, years	1) 0-1, 2) 2-5, 3) 6-10, 4) 11-20, 5) 21-30, 6) $\geq 31$
	Time at home <sup>b</sup>	3) 3 of 5 time periods, 4) 4 of 5 time periods, 5) 5 of 5 time periods
	Usual mode of transportation <sup>a</sup>	1) Walking, 2) Bicycle, 3) Bus/train, 4) Bike/automobile, 5) Taxi/family

<sup>a</sup> Categorical variables <sup>b</sup> Time when the inhabitants were at home during morning (after wake-up)/day (10:00-)/evening (16:00-)/night (19:00-)/midnight (while sleeping)

Table 5 Characteristics of the of respondents questionnaire (valid samples)

	Overall (n=536)		Male (n=238, 44.4%)		Female (n=298, 55.6%)	
	n	%	n	%	n	%
Age, years						
65-69	165	30.8	68	28.6	97	32.6
70-74	127	23.7	58	24.4	69	23.2
75-79	110	20.5	47	19.7	63	21.1
80-84	85	15.9	38	16.0	47	15.8
85-89	34	6.3	20	8.4	14	4.7
90-	15	2.8	7	2.9	8	2.7
Occupation						
Full-time homemaker	193	36.0	9	3.8	184	61.7
Not employed / retired person	322	60.1	221	92.9	101	33.9
Other	21	3.9	8	3.4	13	4.4
Length of residence, years						
0-1	5	0.9	2	0.8	3	1.0
2-5	26	4.9	11	4.6	15	5.0
6-10	36	6.7	17	7.1	19	6.4
11-20	71	13.2	36	15.1	35	11.7
21-30	99	18.5	45	18.9	54	18.1
$\geq 31$	299	55.8	127	53.4	172	57.7
Time at home						
3 of 5 time periods	46	8.6	27	11.3	19	6.4
4 of 5 time periods	125	23.3	53	22.3	72	24.2
5 of 5 time periods	365	68.1	158	66.4	207	69.5
Usual mode of transportation						
Walking	36	6.7	7	2.9	29	9.7
Bicycle	73	13.6	24	10.1	49	16.4
Bus/train	3	0.6	1	0.4	2	0.7
Bike/automobile	330	61.6	183	76.9	147	49.3
Taxi/family	94	17.5	23	9.7	71	23.8

Table 6 Odds ratios for vigorous physical activity, by housing and community environment

	Adjusted OR <sup>a</sup> (95% CI)		P value <sup>b</sup>
<b>Housing environment</b>			
Indoor/outdoor sound and vibration in living room <sup>c</sup>	1.39	(1.09 – 1.75)	**
<b>Community environment</b>			
Participation in community or neighborhood activities <sup>d</sup>	2.24	(1.71 – 2.95)	***
Acquaintance with neighbors <sup>e</sup>	1.67	(1.23 – 2.27)	***
Communication and interaction with neighbors <sup>e</sup>	1.54	(1.11 – 2.13)	**
Walking and sports <sup>d</sup>	1.45	(1.25 – 1.68)	***
Usability of meeting facilities and libraries <sup>e</sup>	1.41	(1.10 – 1.82)	**
Aesthetic aspects of townscape and view <sup>e</sup>	1.39	(1.07 – 1.80)	*
Use of meeting facilities and libraries <sup>d</sup>	1.39	(1.17 – 1.66)	***
Use of bicycles <sup>d</sup>	1.37	(1.18 – 1.59)	***
Use of public transportation systems <sup>d</sup>	1.39	(1.08 – 1.79)	**
Use of exercise facilities <sup>d</sup>	1.33	(1.14 – 1.56)	***
Participation in cultural or lifetime activities <sup>d</sup>	1.22	(1.01 – 1.47)	*
Use of parks, public squares, and promenades <sup>d</sup>	1.16	(1.00 – 1.35)	*
Crowdedness or population density <sup>c</sup>	.731	(.549 – .973)	*

ORs, odds ratios; CI, confidence interval. <sup>a</sup> Adjusted ORs were calculated after adjustment for sex, age, length of residence, time at home, and usual mode of transportation. <sup>b</sup> \*,  $p < 0.05$ , \*\*,  $p < 0.01$ , \*\*\*,  $p < 0.001$ . <sup>c</sup> 0) Very often, 1) Often, 2) Seldom, 3) Never <sup>d</sup> 0) Never, 1) Seldom, 2) Occasionally, 3) Often, 4) Very often. <sup>e</sup> 0) Very poor, 1) Poor, 2) Good, 3) Very good.



was daily step count, and the independent variables were mean temperature (model 1), minimum temperature (model 2), and temperature difference (model 3) for each room in which measurements were taken. Variables considered in the models were basal metabolism, age, sex, household income, educational attainment, and outdoor air temperature. In addition, the measurement data on room temperature and daily step count were input into the models for each participant. The analysis targets were 15 participants (Table 8) who were elderly ( $\geq 65$  years), who had normal body mass index ( $18.5\text{--}25.0\text{ kg/m}^2$ ), and who were not in regular employment.

## **4.2. Results of multiple regression analysis**

### **4.2.1. Relations of mean and minimum temperatures with daily step count**

Multiple regression of the mean and minimum temperatures in each room on daily step count revealed that the mean temperature in the lavatory had a significant correlation with daily step count (Table 9, model 1). Also significant was the correlation between daily step count and minimum temperature in the lavatory (Table 9, model 2). These results indicate that higher mean and minimum temperatures in the lavatory are associated with higher physical activity by residents.

Independent variables input for adjustment were deselected in the models, except for age and household income. Also, when standardized partial regression coefficients were compared, the coefficient on temperature in models 1 and 2 was similarly higher than that on household income. These results indicate that mean and minimum temperatures have a stronger impact on daily step count than do household income, educational attainment, and outdoor air temperature.

### **4.2.2. Relation of temperature difference and steps**

Multiple regression of the temperature differences between rooms on daily step count revealed that the temperature differences between the living room and the three other rooms (lavatory, bedroom, and corridor) had insignificant correlations with daily step count.

Of all the parameters, the temperature difference between the living room and the lavatory had the most significant and strongest correlation with daily step count (Table 9, model 3). This result indicates that a smaller temperature difference between living room and lavatory is associated with higher physical activity by inhabitants.

Independent variables input for adjustment were deselected in the models, except for age and educational attainment. Also, when standardized partial regression coefficients were compared, the coefficient on the temperature difference was higher than of the coefficient on educational attainment. These results indicate that temperature differences have a stronger impact on daily step count than do household income, educational attainment, and outdoor air temperature.

### **4.2.3. Discussion**

Taken together, these results indicate that an indoor thermal environment in which the mean and minimum temperatures in the lavatory are high and the temperature differences between

Table 7 Overview of multiple regression analysis

	Model 1 Mean temperature	Model 2 Minimum temperature	Model 3 Temperature difference
Dependent variable	Daily step count ,steps/day	Daily step count ,steps/day	Daily step count ,steps/day
Independent variable	Mean temperature ,°C	Minimum temperature ,°C	Temperature difference ,°C
Independent variable (input in all models for adjustment of individual attributes)	Basal metabolism Age, years Sex Household income, million yen Educational attainment Outdoor air temperature <sup>a</sup>	kcal 1) 65-69, 2) 70-79, 3) ≥80 1) Male, 2) Female 1) <1, 2) 1-3, 3) >3 1) Junior high school, 2) High school or more °C	

<sup>a</sup> Model 1, 3: mean outdoor air temperature, Model 2: minimum outdoor air temperature

Table 8 Participant attributes (valid samples)

	Overall (n=15)		Male (n=13, 86.7%)		Female (n=2, 13.3%)	
	n	%	n	%	n	%
Age, years						
65-69	6	40.0	5	38.5	1	50.0
70-79	6	40.0	6	46.2	0	0.0
≥80	3	20.0	2	15.4	1	50.0
Occupation						
Full-time homemaker	1	6.7	0	0.0	1	50.0
Not employed / retired	14	93.3	13	100.0	1	50.0
Household income, million yen						
<1	1	6.7	1	7.7	0	0.0
1-3	10	66.7	9	69.2	1	50.0
>3	4	26.7	3	23.1	1	50.0
Educational attainment						
Junior high school	4	26.7	3	23.1	1	50.0
High school or more	11	73.3	10	76.9	1	50.0

Table 9 Partial regression coefficients for daily step count

	Partial regression coefficient (95% CI)	Standardized partial regression coefficient	P value <sup>a</sup>
<b>Model 1 <sup>b</sup> (n=156)</b>			
Const.	15790		***
Age [-]	-195 ( -262 — -128)	-.398	***
Household income [-]	-1964 (-3180 — -749)	-.233	**
<b>Mean temperature in lavatory [°C]</b>	<b>809 ( 407 — 1211)</b>	.286	***
<b>Model 2 <sup>c</sup> (n=156)</b>			
Const.	18181		***
Age [-]	-190 ( -258 — -123)	-.389	***
Household income [-]	-1829 (-3037 — -622)	-.217	**
<b>Minimum temperature in lavatory [°C]</b>	<b>624 ( 293 — 955)</b>	.267	***
<b>Model 3 <sup>d</sup> (n=156)</b>			
Const.	22752		***
Age [-]	-261 ( -339 — -183)	-.533	***
Educational attainment [-]	1861 ( 557 — 3166)	.215	**
<b>Temperature difference between living room and lavatory [°C]</b>	<b>-484 ( -702 — -266)</b>	-.350	***

CI, confidence interval.

Adjusted R-square: model 1, 0.280; model 2, 0.272; model 3, 0.291.

<sup>a</sup> \*\*, p<0.01; \*\*\*, p<0.001.

<sup>b</sup> Basal metabolism, sex, educational attainment, and mean outdoor air temperature were deselected in the model.

<sup>c</sup> Basal metabolism, sex, educational attainment, and mean outdoor air temperature were deselected in the model.

<sup>d</sup> Basal metabolism, sex, household income, and mean outdoor air temperature were deselected in the model.



the living room and the other rooms (especially the lavatory) are small is effective for promotion of physical activity.

The analysis revealed that the indoor thermal environment in the lavatory in particular had a significant correlation with daily step count, indicating that warm non-living-room spaces and small differences in temperature between the living room and other spaces are effective for promotion of physical activity, because the lavatory is considered representative of non-living-room spaces where air heating is seldom used.

## 5. Conclusions

In this field study, we conducted a questionnaire survey and actual measurements to statistically analyze the relations of housing and community environment with physical activity. The following results were obtained.

- 1) In regard to the housing environment, indoor/outdoor sound and vibration in the living room was correlated with physical activity. As for community environment, participation in community or neighborhood activities, usability of meeting facilities and libraries, aesthetic aspects of townscape and view, and high-density housing are thought to be effective for promotion of physical activity.
- 2) An indoor thermal environment in which the mean and minimum temperatures in the lavatory were high and the temperature differences between the living room and the other rooms were small was found to be effective for promotion of physical activity.

## Acknowledgments

This study was carried out with assistance from Japan Science and Technology Agency Strategic Basic Research Programs (Science and Technology for Society) “*Housing and Healthy Aging* (principal investigator: Toshiharu Ikaga)”. The authors thank the members of the Izumigawa Community Planning Conference and the survey respondents.

## Note

We conducted all analyses using IBM SPSS Statistics version 22.

## References

- [1] Ministry of Health, Labor and Welfare (2013). Kenko Nippon 21 (second) <http://www.kenkounippon21.gr.jp/> (Last access day: 2014.5.22)
- [2] Institute for Building Environment and Energy Conservation (2011). CASBEE Health Checklist. [http://www.ibec.or.jp/CASBEE/casbee\\_health/index\\_health.htm](http://www.ibec.or.jp/CASBEE/casbee_health/index_health.htm) (Last access day: 2014.5.22)
- [3] Institute for Building Environment and Energy Conservation (2013). CASBEE Community Health Checklist. [http://www.ibec.or.jp/CASBEE/casbee\\_health/index\\_health.htm](http://www.ibec.or.jp/CASBEE/casbee_health/index_health.htm) (Last access day: 2014.5.22)
- [4] Craig C.L., Marshall A.L., Sjöström M., Bauman A.E., Booth M.L., Ainsworth B.E., et al. (2003). International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc.* 35, 1381-1395, doi:10.1079.

## Music for everyone: “building the space where the differences co-exist”

Avila-Haro, Beatriz E.<sup>1</sup>; Avila-Haro, Jorge A.<sup>2</sup>; Avila, Jorge A.<sup>3</sup>

<sup>1</sup> Faculty of Architecture, National University of Mexico (UNAM)

<sup>2</sup> RMEE Technical University of Catalonia, Barcelona, Spain

<sup>3</sup> Institute of Engineering, National University of Mexico (UNAM)

**Abstract:** *We create environments to be used by people, and any interaction problem between that product and the user is a consequence of an inadequate design. Nowadays architecture is mostly oriented to the search of innovative solutions where the creativity is not necessarily committed to the human necessities. Music allows us to experiment with its different alternatives, harmonies and rhythms. If music has been able to please any demand for decades, architecture could be flexible for the actual needs, letting us see, hear, feel, touch and taste the architecture that surround us. This work pretends to create a design for everyone, for every life period and as a result the creation of an architecture, read under different criteria, and experienced of different ways.*

**Keywords:** *universal design, sensitive architecture, music*

### Introduction

For decades, the architects have formed and designed spaces respecting the guidelines and dimensions established in manuals that are only capable to recognize a perfect and immutable user, who is able to adapt to those proposed spaces. Nevertheless, the surrounding reality is different and we have to open our eyes to notice that we have been designing for a user that is not real; in order to be able to freely and personally develop in the proposed architecture, the human being should be perceived as a user with different necessities and challenges.

The intention of this work is to cooperate in the huge task of dignifying human life and to contribute in the erection of a wall against the waves of dehumanization and vulgarity. It must be understood that architecture can only be considered as complete due to the intervention of the human being, who experiments and brings it to life, but if we don't understand that the human being is extremely diverse as well as its necessities and requirements, our duty as architects will not be accomplished [1].

### Objectives and scope

For this work, the strategic selection of the location with its current problems, the evolution of the design, and the architectonic proposal that demonstrates that architecture can be an element that allows to forget our differences and therefore to share a common space in which we can create a full social life, are presented.

The task of an architect is to create spaces that receive the human being as it is, understanding the different problems that its environment can present and discovering which could our best

contribution be without any negative impact on the ambience. The adjustment of spaces for the existent human diversity, pretends to use design methods that allow the inclusion of users into society and not only its accessibility.

Music, as an inspiration, demonstrates us that since we are born and for many decades is an important factor in our lives, allowing us to establish a communication method to unite masses of people that adapts to the diverse necessities and requirements, influencing our human behaviour.

## **Methodology**

### **Universal design criteria**

The universal design is a design paradigm relatively new, which is focused on the development of easy access products, and environments for as many people as possible, without the necessity of adapting or re-designing them in any special way.

This concept emerges from the design without bounds, in which the universal design has a full accessibility spectra range. The purpose of the universal design is to simplify the everyday tasks of the user through the development of products, services and reusable environments, which is intended to benefit users of all ages and necessities [2].

The points to be covered on the design are: a) Equal use, b) Flexibility, c) Simple and intuitive, d) Information easy to perceive and interpret, e) Scarce physical effort, f) Appropriate dimensions and g) In-situ materials reuse.

### **Music ¿why?**

Music, is an effective method to communicate values and global identities. It transmits a message that is understood by everyone, giving a sense of belonging.

Music is a topic that has had deep impact along our life and it has allowed us to experiment with its different alternatives, styles, harmonies and rhythms. For decades, music has been able to satisfy any demand, therefore, architecture could be flexible to the current needs; allowing us to see, listen, feel, touch and taste the architecture that surround us.

### **The project**

The universal design basis proposed herein pursuits a design “for everyone and for every period of life”, where senses become the guidelines to read the proposed spaces and, as a result, an architecture for different criteria is created and experienced in diverse ways.

The project is developed in San Juan de Aragón forest, which has an approximate territorial extension of 158.5 hectares. It is located in the border of the Gustavo A. Madero district in Mexico City, Mexico.

The complex is conformed of 8 buildings with one to two stories, strategically located in different platforms and unevenness as a result of the previous analyses, the activity to be developed, and the sensory proposal of each one. In order to establish a clear interior and



exterior spatial, structural and constructive distribution, a module design was used for each building.

The main function of the sensoriality theme is to propose a method that let us read the spaces and use each of our senses to accomplish a more rich experience outside of the ordinary. Architecture proposes the enrichment of our sensations by different criteria and diverse ways of experience it.

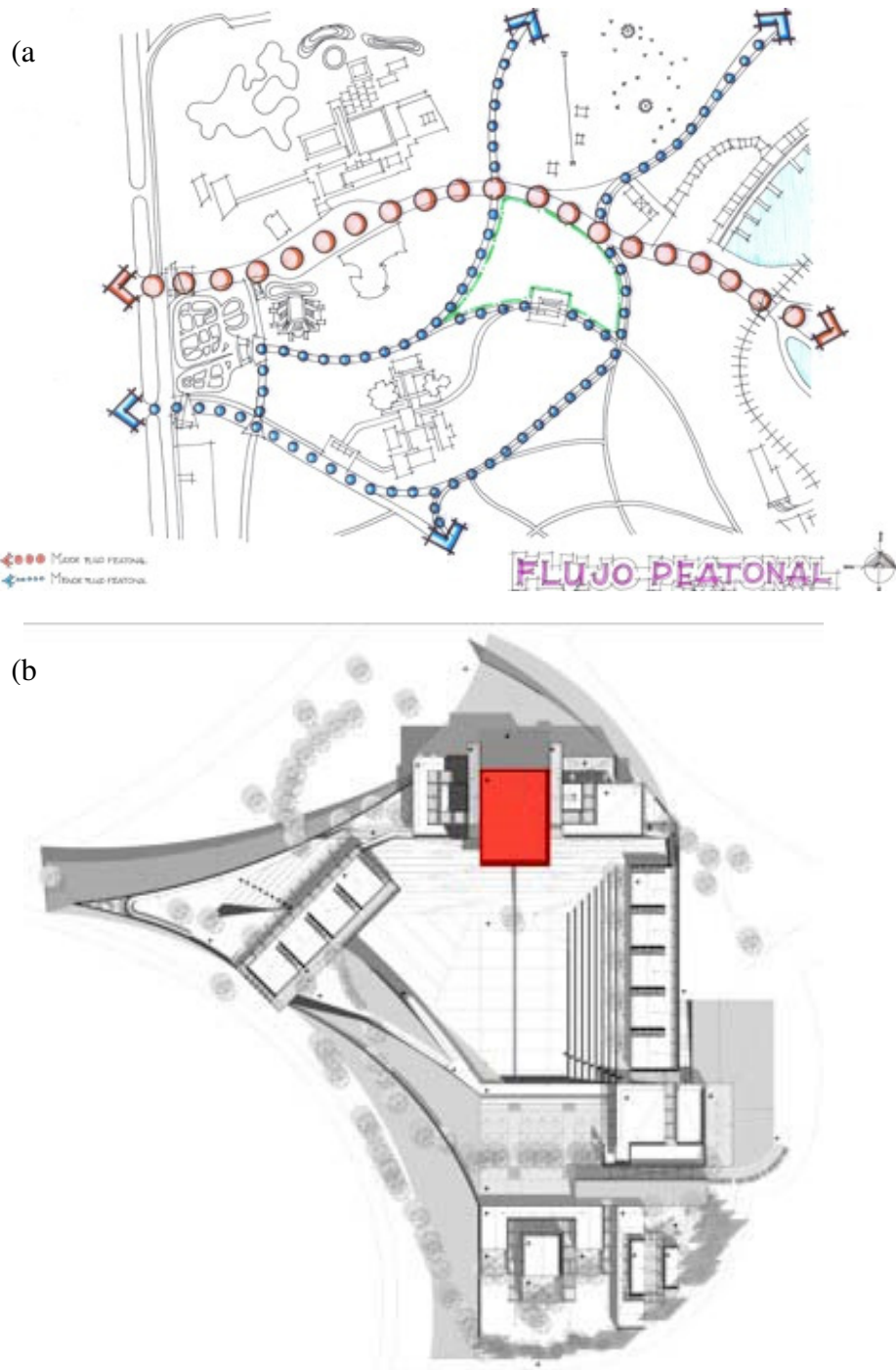


Figure 1: Site analysis: (a) pedestrian flow, and (b) plan set

- Service building 1 (secondary auditoriums)  
Total capacity: 170 users. Total area: 616.48 m<sup>2</sup>

- Main auditorium  
Total capacity: 225 users. Total area: 481.89 m<sup>2</sup>

- Service building 2 (bookshop)  
Total capacity: 135 users. Total area: 727.63 m<sup>2</sup>

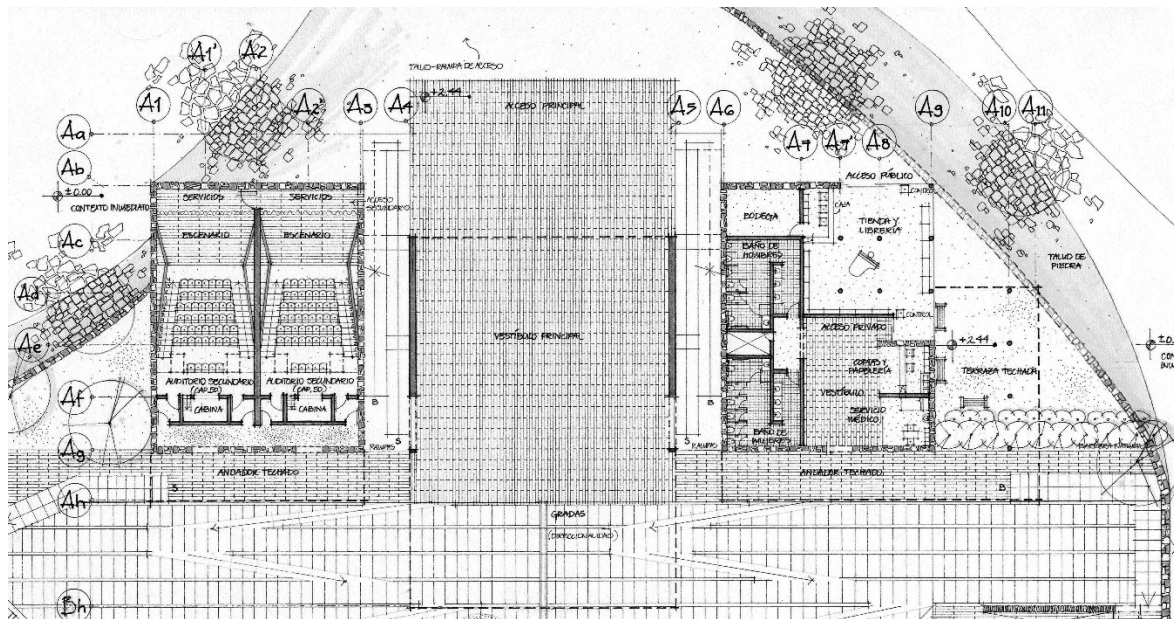
- Instrumental practice classrooms  
Total capacity: 60 users. Total area: 725.26 m<sup>2</sup>

- Cafeteria  
Total capacity: 130 users. Total area: 1,161.37 m<sup>2</sup> (Terraces: 721.67 m<sup>2</sup>)

- Music therapy centre  
Total capacity: 80 users. Total area: 1,147.63 m<sup>2</sup>

- Theoretical lessons classrooms  
Total capacity: 40 users. Total area: 772.61 m<sup>2</sup>

- Library  
Total capacity: 100 users. Total area: 1,010.95 m<sup>2</sup>



ISBN: 978-84-697-1815-5

ERROR: stackunderflow  
OFFENDING COMMAND: ~

STACK:

## Embodied energy and embodied CO<sub>2</sub> associated with buildings based on detail analysis and simple analysis

Yokoo, Noriyoshi(NY)<sup>1</sup>; Ito, Naomi (NI)<sup>2</sup>; Oka, Tatsuo (TO)<sup>3</sup>

<sup>1</sup> Utsunomiya University, Utsunomiya, Japan

<sup>2</sup> Utsunomiya University, Utsunomiya, Japan,

<sup>3</sup> Professor Emeritus, Utsunomiya, Japan

**Abstract:** Many energy saving strategies are implemented in the architectural community, zero energy buildings and carbon neutral buildings and so on. Most of strategies are focus on operating energy and CO<sub>2</sub> emissions. Embodied energy / CO<sub>2</sub> occupy about 19% of total energy or CO<sub>2</sub> in Japan. The weight of the energy consumption and CO<sub>2</sub> emissions due to building construction is increasing, so that methods used to estimate these factors will become increasingly important.

This study analysis embodied energy / CO<sub>2</sub> associated with low carbon building in Japan and proceeded detail analysis and simple analysis, to demonstrate appropriate assessment scale at the analysis of embodied energy / CO<sub>2</sub>. The detail analysis covers all building components and materials; site works, structure, envelop, opening, finishing, mechanical services, electric services, sanitary services and so on. The simple analysis covers main building components and materials; structure, part of envelope.

The results show that embodied energy / CO<sub>2</sub> by detail analysis is about 12.5GJ/m<sup>2</sup>, 1180kg-CO<sub>2</sub>/m<sup>2</sup>, and by simple analysis is about 5.2 GJ/m<sup>2</sup>, 550kg-CO<sub>2</sub>/m<sup>2</sup>.

Embodied energy / CO<sub>2</sub> of structure are dominant and it occupies about 60% of total embodied energy / CO<sub>2</sub> in detail analysis. Embodied energy / CO<sub>2</sub> of mechanical, electrical services occupies about 10% of total, so it is important to cover these elements of building.

**Key words:** Embodied energy, Embodied CO<sub>2</sub>, IO analysis, Low carbon building

### 1. Introduction

Many energy saving strategies are implemented in the architectural community, zero energy buildings and carbon neutral buildings and so on. Most of strategies are focus on operating energy and CO<sub>2</sub> emissions. Embodied energy and CO<sub>2</sub> occupy about 19% of total energy or CO<sub>2</sub> in Japan. The weight of the energy consumption and CO<sub>2</sub> emissions due to building construction is increasing, so that methods used to estimate these factors will become increasingly important.

This study analysis embodied energy / CO<sub>2</sub> associated with low carbon building in Japan and proceeded detail analysis and simplified analysis, to demonstrate appropriate assessment scale at the analysis of embodied energy / CO<sub>2</sub>. The detail analysis covers all building components and materials; site works, structure, envelop, opening, finishing, mechanical services, electric services, sanitary services and so on. The simple analysis covers main building components and materials; structure, part of envelope.

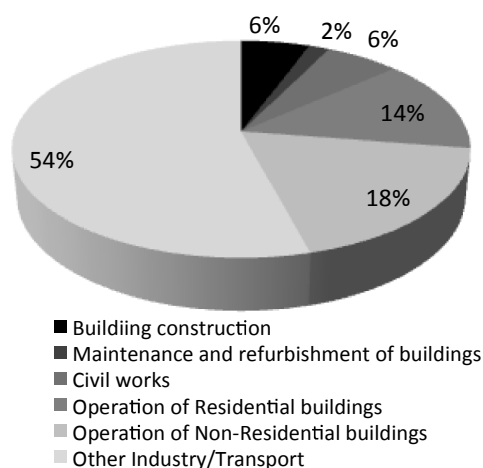


Fig. 1 Fraction of CO<sub>2</sub> Emissions in Japan

It is important to focus on the environmental impacts due to both building construction and operation. This study demonstrate embodied energy and embodied CO<sub>2</sub> as one of environmental impact examples, and the intention of this study is to enhancing awareness on embodied impact as same as operation impact.

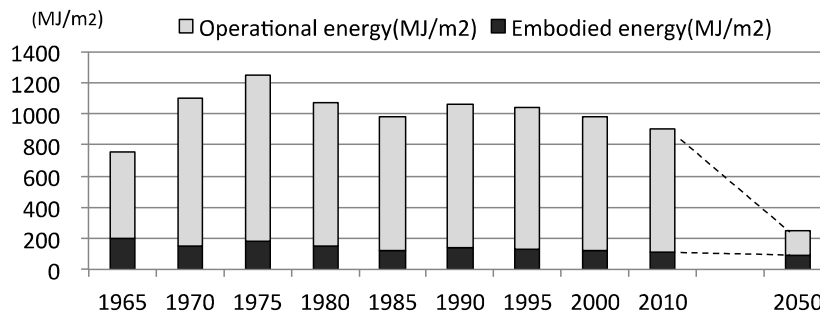


Fig. 2 Trend of the Embodied energy and operating energy of office buildings

## 2. Importance of embodied energy and embodied CO<sub>2</sub> due to building construction

CO<sub>2</sub> emission of Japan is about 12 billion ton-CO<sub>2</sub> and energy and CO<sub>2</sub> associated with building sector of Japan occupies about 46%, embodied energy and CO<sub>2</sub> associated with buildings including maintenance and civil engineering structures about 14%.

Since 1965 the trend of operating energy consumption and CO<sub>2</sub> emission of office buildings are decreased year by year, and latest energy saving and low carbon strategies mainly focuses on operating energy and enhancing to achieve zero energy buildings. According to these trends, it is expected that embodied energy and embodied CO<sub>2</sub> will be more important issues in near future when compared to today.

## 3. Summary of Case study buildings

Three different structure buildings were evaluated, and Office B is a prefectural government office and it introduces various energy saving strategies and long life strategies to achieve low carbon building. Main energy saving designs s are passive design, natural ventilation, double skin façade, day-lighting, high efficiency mechanical system, PV panel, thermal storage, active control earthquake. Main low carbon and long life design strategies are shown Table2

Table 1 Summary of case study buildings

	Office A	Office B	Office C
Structure	Steel	Steel and RC	RC
Number of floor	6 F	15, 2 BF	3 F
Total floor area	8,000 m <sup>2</sup>	64,000	1,100



Table 2 Long life design strategies in Office B

	Long life / Low carbon strategies Office B	Standard buildings Office A, Office C
Earthquake resistant strength	Increase steel frame	Standard
Longevity	Oil dumper to reduce earthquake response acceleration	No dumper
	Increase covering depth of concrete	Standard covering depth
	Tile exterior Wall	Paint finishing exterior walls
	Stainless Steel piping for water works	Steel piping
Reduce heat loads	Double skin facade,	Single glazing
Passive design	Low-e glazing	No atrium, no light court
Peak-shift of energy demand	Thermal storage tank	No
Maintenance	Cat-walk	No
Renewable energy/ resource savings	PV panel, Rain water collection	No

Table 3 Building materials quantities in Office B

Main building materials	Quantities
Concrete	49,000 m3
Reinforce bar	6,581 t
Steel frame	3,026 t
Aluminum panel	780 t
Single glazing	4,736 m2
Double glazing	2,363 m2
Glass wool	17,427 m2
Carpet tile	22,612 m2
Tiles and ceramics	16,057 m2

#### 4. Embodied energy and embodied CO<sub>2</sub> due to Low carbon building construction

##### 4.1 Method

There are several methods to calculate embodied energy and embodied CO<sub>2</sub>, like process based analysis and I-O based analysis. In Japan, the government publishes I-O table every 5 years and it covers more than 400 industrial sectors. This study uses 2005 I-O table which latest published, and obtained energy intensities and CO<sub>2</sub> intensities of main building materials and components. This study also collects building material quantity data based on the cost estimation sheet data and obtained embodied energy and embodied CO<sub>2</sub> by multiplying building quantity data and energy intensities and CO<sub>2</sub> intensities.

All impacts from the raw material extraction and the manufacturing of the building materials are included, because the calculation is based on intensity of 2005 I-O table in Japan.

The calculation method is as follows;

The embodied energy /CO<sub>2</sub> is obtained from the analysis 2005 I-O tables in Japan. The I-O tables of Japan consist of 400 industrial sectors. Building materials and quantities data are obtained by using building cost data. Reference building are assumed based on standard design. Long life and low carbon office considers design strategies shown in Table 1 and compare long life/Low carbon office and reference building. Embodied energy and Embodied CO<sub>2</sub> of all element of building, part of elements of building and of skeleton.

#### 4.2 Building elements and whole building

The study analyses each building element, Skelton, Finishing, Equipment. The study analyses the buildings based on detail analysis, semi-detail analysis and simple analysis (Table 4 and Table 5).

Many of existing research on the embodied energy / CO<sub>2</sub> conducted simple analysis or semi-detail analysis. This study tries to illustrate gap among detail analysis, semi-detail analysis and simple analysis.

Table 4 Assessment boundary and Building elements

Evaluation frame	Building parts to be evaluated
Detailed evaluation	Structure, Interior finishing, Exterior finishing, Mechanical, Electrical and Sanitary systems
Semi-detailed evaluation	One of structure, interior finishing, exterior finishing and systems
Simple evaluation	Foundation and building frame

Table 5 Building elements to be evaluated in detail analysis

Building elements	Building parts to be evaluated
Structure	Foundation, Reinforced bar, Concrete Steel frame, Flooring work, Fireproof covering, others
Exterior finishing	Roof, aperture/fixture, Exterior wall, others
Interior finishing	Floor finishing, Ceiling finishing, Wall finishing, others
Service systems	Heating and cooling systems, piping and duct works Sanitary and plumbing systems, Electrical and lighting systems

Table 6 Number of building materials to be evaluated in detail, semi-detail and simple analysis

Building elements	Building components	Number of materials and components to be evaluated								
		Office A			Office B			Office C		
		Detail	Semi-detail	Simple	Detail	Semi-detail	Simple	Detail	Semi-detail	Simple
Structure	Foundation	3	2	3	3	3	3	3	3	3
	Reinforced bar	2	2	2	1	1	1	2	2	2
	Concrete	1	1	1	1	1	1	1	1	1
	Steel frame	9	3	9	5	3	5	4	3	4
	Flooring work	1	1	1	4	3	4	2	2	2
	Fireproof film	1	1	1	6	3	6	0	0	0
	Others	0	0	0	5	3	5	3	3	3
Exterior finishing	Roof	13	3	0	20	3	0	14	3	0
	Aperture/fixture	20	3	0	17	3	0	18	3	0
	Exterior wall	16	3	0	23	3	0	16	3	0
	Others	4	3	0	0	0	0	4	3	0
Interior finishing	Floor finishing	24	3	0	18	3	0	20	3	0
	Ceiling finishing	10	3	0	9	3	0	8	3	0
	Wall finishing	32	3	0	31	3	0	30	3	0
	Others	3	3	0	9	3	0	1	1	0
Service systems	Heating/cooling	37	3	0	18	3	0	31	3	0
	Sanitary	31	3	0	108	3	0	32	3	0
	Electrical	76	3	0	11	3	0	69	3	0
	Total	283	43	17	284	47	25	258	34	15



## 5. Results

### 5.1 Detail analysis

Embodied energy results are 11,939 (MJ/m<sup>2</sup>) for Office A, 7,743 (MJ/m<sup>2</sup>) for Office B and 10,835 (MJ/m<sup>2</sup>) for Office C. Embodied CO<sub>2</sub> results are 1,031(kg-CO<sub>2</sub>/m<sup>2</sup>) for Office A, 1,033(kg-CO<sub>2</sub>/m<sup>2</sup>) for Office B, for 843 (kg-CO<sub>2</sub>/m<sup>2</sup>) for Office C.

Fig. 4 shows that the breakdown of embodied energy of main building elements. Exterior wall of Office A is larger than the others because Office A uses curtain wall which consumes high-energy intensity materials as exterior walls. Embodied energy of the building frame occupies about 70% in Office B and Office C. The calculation results of Embodied CO<sub>2</sub> show similar trend of embodied energy.

Fig. 5 shows that the comparative results of embodied energy by detail, semi-detail and simple analysis.

### 5.2 Semi detail analysis

Based on the results of the detailed analysis, first three high-energy intensity materials are chosen in each building components and evaluation were conducted as semi detail analysis.

Embodied energy results are 8,972 (MJ/m<sup>2</sup>) for Office A, 9,745 (MJ/m<sup>2</sup>) for Office B and 5,287 (MJ/m<sup>2</sup>) for Office C. Embodied CO<sub>2</sub> results are 806 (kg-CO<sub>2</sub>/m<sup>2</sup>) for Office A, 911 (kg-CO<sub>2</sub>/m<sup>2</sup>) for Office B, 616 (kg-CO<sub>2</sub>/m<sup>2</sup>) for Office C.

### 5.3 Simple analysis

Simple analysis evaluates the foundation and the frame of the buildings. Embodied energy results are 4,869 (MJ/m<sup>2</sup>) for Office A, 7,616 (MJ/m<sup>2</sup>) for Office B and 4,366 (MJ/m<sup>2</sup>) for Office C. Embodied CO<sub>2</sub> results are 473 (kg-CO<sub>2</sub>/m<sup>2</sup>) for Office A, 744 (kg-CO<sub>2</sub>/m<sup>2</sup>) for Office B, 497 (kg-CO<sub>2</sub>/m<sup>2</sup>) for Office C.

## 6. Conclusion

This study describes the trend of energy and CO<sub>2</sub> relating to building construction and illustrates of the importance of embodied energy / CO<sub>2</sub>, and differences among the evaluation boundary settings what building part should be included in the embodied energy / CO<sub>2</sub> evaluation.

The results suggested that calculation results brought large differences due to differences in building evaluation range from the case of all building components evaluation to the case of only frame of building evaluation.

The semi-detail analysis could evaluate 90% of embodied energy/ CO<sub>2</sub>. However the simple analysis could only evaluate less than 60% of embodied energy / CO<sub>2</sub>, compare to the detail analysis in the steel frame structure building and the reinforcing concrete buildings.

It is taken into account what part of building components included or exclude when the embodied energy /CO<sub>2</sub> of buildings are investigated.

This study demonstrates the embodied energy / CO<sub>2</sub> as one of environmental impact examples, and tried to enhance awareness on the embodied impact as well as operation impact. This study only deals with energy and CO<sub>2</sub>, however there is other environmental impacts which should be included for the embodied impact evaluation, and the further research will be implemented to cover whole environmental impacts to assist improving building environmental performance.

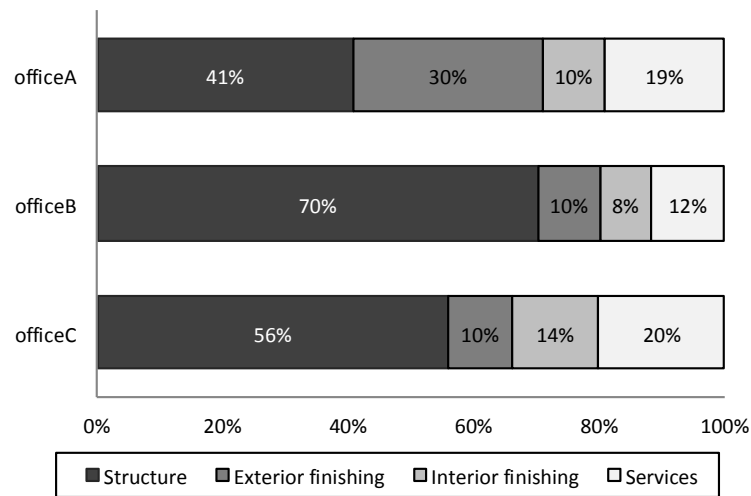


Fig. 4 Embodied energy and portion of building elements in detail analysis

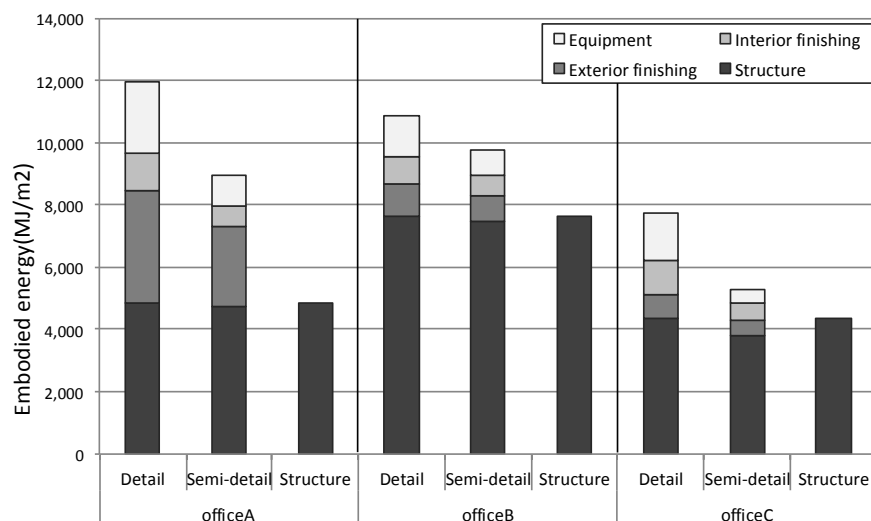


Fig. 5 Comparison on embodied energy by detail, semi-detail and simple analysis analysis

## References

- 1) T. Ramesh: Life cycle energy analysis of buildings: An overview, Energy and Buildings, 42, 2010
- 2) Dixit: Need for an embodied energy measurement protocol for buildings, Renewable and Sustainable Energy Reviews, 2012
- 3) R. Cole: Life-Cycle Energy Use in Office Buildings, 1996
- 4) R. Fay: Life-cycle energy analysis of buildings: a case study, (2000)
- 5) L. Gustavsson, Life Cycle primary energy use and carbon emissions of an eight -story wood-frame apartment building, Energy and Buildings, 42, 2010

## **Characterization of thermal insulation materials developed with crop wastes and natural binders**

Mariana Palumbo<sup>1</sup>, Antonia Navarro<sup>1</sup>, Jaume Avellaneda<sup>2</sup>, Ana Maria Lacasta<sup>1</sup>

<sup>1</sup> Barcelona School of Building Construction, Universitat Politècnica de Catalunya, Barcelona, Spain

<sup>2</sup> Escola Tècnica Superior d'Arquitectura del Vallès, Universitat Politècnica de Catalunya, Sant Cugat del Vallès, Spain.

### ***Abstract:***

*This paper seeks to discuss the possibility of developing insulation materials for the construction sector made of non-industrial crop wastes and natural binders. Three different crop wastes widely available in Spain, namely barley straw, corn pith and rice husk, are used in the production of experimental insulation panels. Their thermal behaviour, equilibrium moisture content and water vapour permeability are assessed in order to determine their suitability as a construction insulation material. Results show that crop wastes can perform adequately as insulation materials with any or little manipulation. They also reflect how the choice of the crop waste affects the characteristics of the final products.*

***Sustainable construction materials, natural fibres insulations, crop wastes, hygrothermal behaviour***

### **1. Introduction**

The intervention on the existing building stock is a vital tool to face the challenge of reducing CO<sub>2</sub> emissions established by the European Commission for 2020 and 2050. Existing buildings consume about 40% of EU's total annual energy consumption, mainly for heating and air conditioning and the implementation of optimized thermal insulation systems on these buildings is regarded as one of the main strategies to improve their energy efficiency [1,2].

By 2050, in line with European GHG reduction scenario, about 10 million houses in Spain need to be insulated. [3]. Therefore, the energy as well as the depletion of non-renewable natural resources associated to their production are important factors to take into account. [2]

Actually, the increasing consciousness on the hazardous effects that certain insulation building materials have both to human health and to the environment has inspired a rich research on healthier and renewable options. Recent developments support the use of biomass from industrial crops (mainly hemp, kenaf or flax) as an alternative to petrol based products. Nowadays, these developments have allowed the insertion in the mainstream market of some natural insulation materials such as hemp wools or wood fibres.

Some research has been done as well on the use of non-industrial crop wastes such as straw, stalk cores or husks of cereals [4]. Although many of such research have been focused on the



reinforcement in composites [5], the development of high and medium density boards [6] or the straw bale wall systems [7], there is an increasing interest in their use in natural thermal insulation materials.

Since some pioneering patents from the twenties [8] to the present, many attempts have been done to produce insulation boards. Pinto et al. [9,10] found that exist similitudes between corn cob and EPS regarding their microstructure, but that the thermal conductivity of experimental panels developed with corn cobs presented a higher thermal conductivity than EPS. Similar results were obtained by Dowling et al. [11]. Wang D et al. [12] made experimental low density boards with a mixture of wheat straw and corn pith. Their results show that the equilibrium moisture content is not affected by the density of the sample. They also found that thickness swell is larger than linear expansion due to the orientation of the fibres, parallel to the faces of the board.

Concrete, lime and other inorganic materials are commonly used as binders, dramatically increasing the thermal conductivity of the final product [13]. Organic resins are also generally used, but have negative side effects caused by the emission of volatile organic compounds. Besides, all these binders may increase the embodied energy and prevent the biodegradability of the final product, causing problems of waste disposal or recycling. Binderless panels have been developed, but their production need high pressure, which increases their thermal conductivity. The use of natural binders, e.g. starch or casein, may be an alternative to overcome all these difficulties: the resulting panels are light, formaldehyde free and completely biodegradable.

Vejeliené et al. [14] tested insulation specimens of binderless -tied- wheat straw boards in different configurations and found that boards made of chopped straw (2-4cm long) presented a lower thermal conductivity than those made with the entire stalk. Furthermore, density seemed not to have any impact on thermal conductivity when straw was chopped, but had a significant effect on entire straw. Entire straw at 50kg/m<sup>3</sup> had similar conductivity than chopped straw (about 0,041 W/mK)

Cadena [15] developed insulation boards based on rice husks and yuca starch. They concluded that starch was a suitable binder as it didn't increased the thermal conductivity of the samples as PVA did. The best mixture presented a thermal conductivity of 0.065 W/mK and a density of 194.96 kg/m<sup>3</sup>. Nevertheless, the resistance in front of water had to be improved. No study was found that used alginate as a binder in insulation materials, although it has been used traditionally in earth renders [16] and was used in unfired bricks to increase their compression strength [17].

A significant aspect of natural thermal insulations is their hygroscopicity, that is, their capacity to accumulate moisture by adsorption from the air [18,19,20]. As the adsorption is higher when relative humidity is increased and the excess of moisture is released when humidity is decreased, this behaviour can contribute to regulate the indoor humidity conditions [19]. From the point of view of the performance of building envelope that

incorporates a natural insulation, the knowledge of the material properties is of main importance for a correct evaluation of the whole hygrothermic behaviour. Thermal conductivity, equilibrium moisture content and water vapour permeability are the three main characteristics that, once evaluated, can be incorporated as an input data for simulation programs [19].

In this paper, different crop wastes are considered to analyse their viability to be used as thermal insulators. They have been selected taking into account their availability in Spain. Previous studies showed that barley, wheat, corn and rice waste products are produced in a larger quantity yearly [21]. The vegetal raw materials have been linked by natural organic binders: corn starch, alginate and casein.

## 2. Materials and methods

### 2.1. Vegetable raw materials

Among the available raw materials, three were chosen that presented remarkable morphological differences: barley straw, corn pith and rice husks. Corn stalks contain an interior tissue -the pith- predominantly formed by relatively big parenchyma cellules (diameter about 100-140  $\mu\text{m}$ ) that present a thin cellular wall. Barley straw is hollow and its parenchyma cellules are smaller (diameter from 20 to 40  $\mu\text{m}$  approximately). Figure 1 shows SEM images of the two raw materials. The factors mentioned above would explain the significant lower density of the corn pith (about 13,44kg/m<sup>3</sup>) when compared with the barley straw (estimated at 24,66kg/m<sup>3</sup>). Rice husk is a by-product with little applications at the present. It degrades slowly which makes it very difficult to reintroduce in fields. Lately it's being revalorised for energy production. Rice husk is the densest among the chosen crop wastes: 64,27kg/m<sup>3</sup> and present an important amount of silica [15] [22].

### 2.2. Binder materials

Three different biopolymers were used as binders to produce the panels, two polysaccharide i.g. corn starch and sodium alginate, and a protein: casein.

Corn starch is commonly used in binders and adhesives and thus, it has been widely used in construction, as well as in other industries as packaging and paper making [23]. Alginate is mainly used in cosmetics and food industry, even if a reference was found where it was added to clay bricks [17]. Finally, casein has been used traditionally in construction, it has been widely used as a binder and romans mixed it with mortar to confer consistency and a certain hydrophobicity to the mixture [24].

Corn starch and sodium alginate were provided by Cargill, both presented in the form of a white powder, while casein was provided by the research group Patrimoni-UB (University of Barcelona) in the form of a yellow powder with a strong odour.

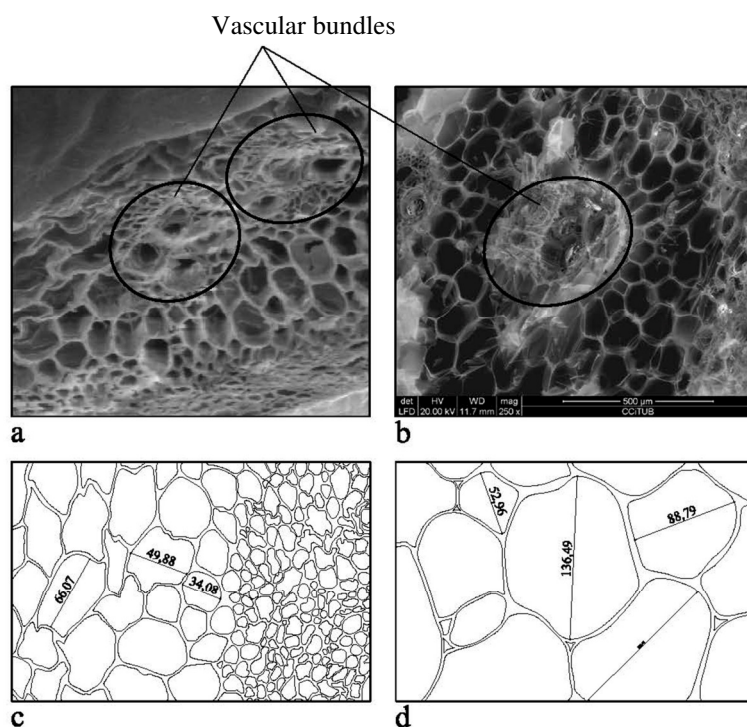


Figure 1. SEM images of barley straw (a) and corn pith (b). Image (a) is scaled four times more than (b). Drawings underneath show both tissues at the same scale, (c) for barley and (d) for corn.

### 2.3. Sample preparation

The external peel of entire corn stalks was manually removed, as well as nodes, to separate the internal pith. Then the pith and the barley straw were chopped separately with a lawnmower and sieved. Rice husk was directly sieved. Particles of 2, 0.5, 1 mm diameter respectively were used in the production of samples. Particle sizes were previously determined taking into account workability and thermal conductivity of the mixtures.

Starch and alginate were mixed with water and a small amount of vinegar (6% acidity) to form a gel. Vinegar and sodium bicarbonate were added to the mixture of water and casein to activate the latter, instead of NaOH and lime usually used.

Samples of two different sizes were prepared for each formulation: 40 x 40 x 2 mm and 150 x 150 x 30 mm. The chosen formulations were obtained from literature and previous work [25]. The aim of this previous work was (1) select the raw materials of study among a wider range of available materials, (2) determine the particle size used in each formulation and (3) reduce

the use of binders and other additives to the minimum necessary to agglomerate the mixture. Table 1 shows the final formulations chosen after this previous work.

	Binder	Water	Vinegar	Sodium bicarbonate
S-Barley (0.5 mm)	0.23	2.28	1.20	
S-Corn (2.0 mm)	0.18	3.02	0.60	
S-Rice (1.0 mm)	1.0	1.17	0.40	
A-Barley (0.5 mm)	0.04	2.76	0.50	
A-Corn (2.0 mm)	0.13	7.87	0.50	
A-Rice (1.0 mm)	0.05	2.21	0.42	
C-Barley (0.5 mm)	0.36	1.64	0.40	0.40
C-Corn	0.11	0.49	0.80	0.40
C-Rice	0.11	0.48	0.33	0.17

*Table 1: Formulations of the experimental natural insulation materials. Values are expressed in grams for 1g of crop waste material*

2.4. Hygroscopic characterization: equilibrium moisture content (EMC) and water vapour diffusivity resistance factor ( $\mu$ )

EMC was experimentally determined by means of the salt solution method for three different RH (36%, 67% and 94%).

Water vapour diffusivity resistance factor ( $\mu$ ) was determined following the standard UNE-EN 12088. A saturated solution of NaOH (18% RH) and  $\text{Na}_2\text{SO}_4$  (95% RH) were used for the dry and wet cups respectively. Samples were weighed regularly for a week or until a linear progression in weigh change was observed.

2.5. Thermal characterization: thermal conductivity and dynamic thermal performance

Thermal conductivity ( $\lambda$ ) and thermal diffusivity ( $\alpha$ ) were measured on the big samples with the electronic thermal analyser, QuicklineTM-30, based on the ASTM D5930 standard, at room conditions. Three measurements were done for each sample.

Dynamic thermal behaviour was also analysed. For this purpose, two thermocouples were used: one of them introduced 15 mm below the surface and the second placed on their surface. Samples were conditioned at 12°C in a fridge until equilibrium was reached. They were then placed in an oven pre-set at 50°C. They were left there for 1.5 hours and then placed again in the fridge for other 1.5 hours.

### 3. Results and discussion

#### 3.1. Hygroscopic characterization

Table 2 show the equilibrium moisture content in weigh percentage (EMC%) of the different samples for the three RH studied. The results obtained for the samples with starch and alginate are similar between them and also similar with those obtained by Collet et al [18] for hemp wools. EMC% in these cases is about ten times higher to those that correspond to a mineral wool [26]. Mixtures containing casein have a remarkable higher EMC% in all RH. Further work has to be accomplished in order to elucidate the reason of these extremely high values.

HR	EMC%			$\mu$	
	36%	67%	94%	Dry cup	Wet cup
S-Barley	2.96	10.13	18.27	11.60	3.80
S-Corn	2.48	9.38	20.62	11.18	3.00
S-Rice	3.21	8.73	14.21	12.71	4.56
A-Barley	2.77	10.37	21.72	10.40	4.00
A-Corn	2.26	13.29	28.96	12.80	2.94
A-Rice	2.74	8.86	16.5	9.87	5.31
C-Barley	5.57	24.64	75.69	11.36	4.19
C-Corn	9.11	38.82	94.15	7.80	3.18
C-Rice	6.34	23.85	67.39	12.05	3.51

TABLE 2. EMC% for different samples and RH.

The kind of vegetal waste also has a remarkable effect on EMC%. Samples containing rice are the ones that absorb less moisture followed by barley and corn pith. Nevertheless, this trend is inverted when the moisture content is expressed per volume ratio instead of mass ratio. This is due to the lowest density of corn mixtures as is shown in Table 3.

Values for water vapour diffusivity resistance factor are also shown in Table 2. As expected, the results obtained by the two methods are different, the wet-cup method producing the higher value [27]. Vapour permeability increases as higher humidities are reached. Results are similar to other natural fibre insulation (NFI) materials such as wood fibres and cork insulation boards which present a  $\mu$  value between 5 and 10 [28]. Nevertheless, hemp fibre usually present a slightly lower  $\mu$  value, between 1 and 3 [18,28], which is more similar to mineral wools.

#### 3.2. Thermal characterization

Table 3 shows densities and thermal conductivity and diffusivity of the nine specimens analysed. Mixtures containing rice husks present the highest thermal conductivity and the ones containing corn pith the lowest, regardless to the binder used. This result is correlated



with the density of the formulations, as rice products are two times denser than corn ones. Regarding the binders, alginate mixtures are less dense and thus present a lower thermal conductivity, while casein seems to increase the thermal conductivity of the mixtures. The best result was for corn and alginate (0.052 W/mK). Results are comparable to wood fibre boards, even if they are higher than other commercially available insulation materials (see Table 3).

As thermal diffusivity is proportional to conductivity and inversely proportional to density, results are similar for all the mixtures.

	$\delta$ (kg/m <sup>3</sup> )	$\lambda$ (W/mK)	$\alpha$ 10 <sup>-6</sup> (m <sup>2</sup> /s)
S-Barley	220	0.075	0.202
S-Corn	160	0.060	0.347
S-Rice	290	0.077	0.330
A-Barley	170	0.066	0.279
A-Corn	80	0.052	0.357
A-Rice	210	0.073	0.332
C-Barley	210	0.074	0.272
C-Corn	140	0.067	0.276
C-Rice	270	0.098	0.377
Mineral wool	20-200	0.035-0.045	-
Expanded polystyrene	15-30	0.035-0.040	-
Extruded polystyrene	25-45	0.030-0.040	-
Wood fibre	30-270	0.040-0.090	-
Hemp wool	20-68	0.040-0.050	-
Cork board	100-220	0.045-0.060	-

Evaluation of the dynamic thermal performance of the materials was also done following the method described in section 2.5. Together with the formulations developed, a sample of rock wool insulation was tested. In general, the temperature inside the sample has a certain delay compared with the temperature of the surface when the sample is changed from the cool chamber to the hot one and vice versa.

All samples containing crop wastes experience a similar behaviour. As an example, Figure 2 shows the change in internal temperature against time for corn alginate, and compares it with a mineral wool. As expected, the lower diffusivity of the mineral wool ( $0.34 \cdot 10^{-6} \text{ m}^2/\text{s}$ ) with respect to that of the A-corn ( $0.36 \cdot 10^{-6} \text{ m}^2/\text{s}$ ) results in a lower slope in temperature change. Nevertheless, at about 40°C, this tendency is inverted as the A-corn sample needs much more time to reach the temperature of the hot chamber. A similar behaviour is observed when the

samples are moved from the hot to the cool chamber. This slowing down in the dynamics is due to the adsorbed-desorbed water vapour in the interior of the fibre matrix and the heating involved in such a process.

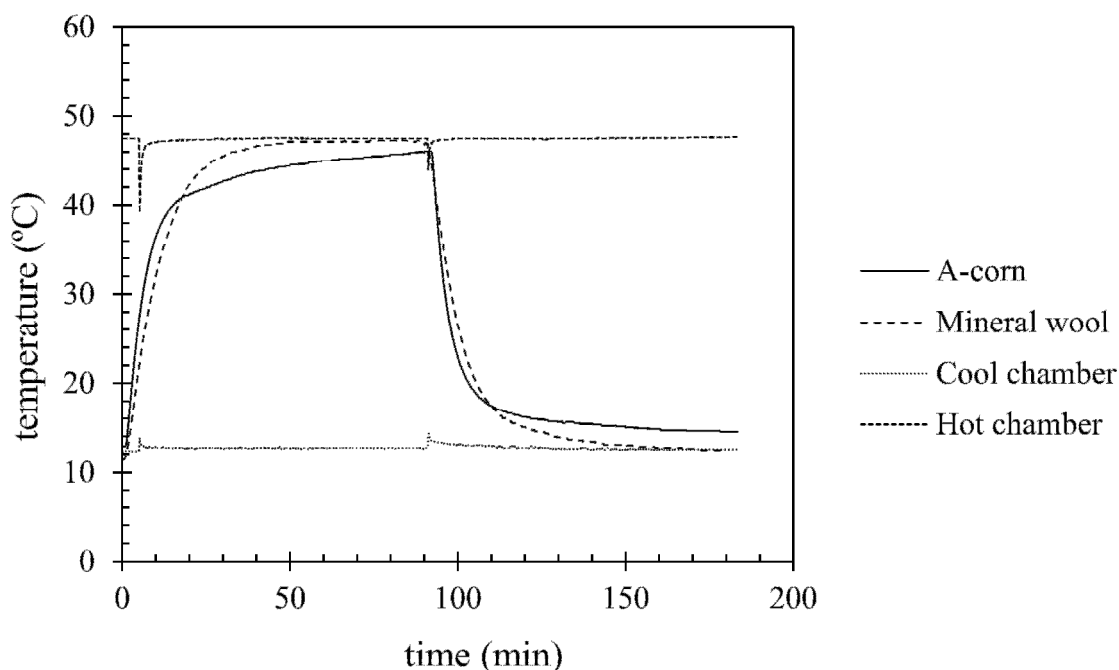


Figure 2: Dynamic thermal behaviour. Internal temperature for A-corn sample is compared with a mineral wool.

#### 4. Conclusions

Different thermal insulation materials based on crop wastes and natural binders were characterised. Their thermal behaviour (both steady state and dynamic), equilibrium moisture content and water vapour permeability were analysed.

The hygroscopicity of the mixtures, measured by the equilibrium moisture content, depends on the specific crop waste used, being mixtures with corn pith the ones with higher values. Mixtures bonded with alginate and starch show similar results while casein seems to substantially increase the moisture sorption of the samples. Water vapour permeability is similar for all the cases and is in agreement with the values found in literature for other fibre insulation materials.

Results for thermal conductivity are acceptable for insulation materials as they are comparable to wood fibre boards, even if they are higher than other commercially available insulation materials such as mineral wools or EPS. The lower value was measured on corn pith bonded with alginate.



The intrinsic hygroscopicity of the natural fibres results on a remarkably different dynamic thermal behaviour when compared with mineral fibres. When environmental temperature increases part of the internal moisture is desorbed. This process involves heat absorption and therefore the increment in sample temperature is lower than expected regarding its thermal diffusivity. The opposite occurs when temperature decreases and moisture is adsorbed. In both cases the thermal inertia of the material is increased.

In conclusion, results show that crop wastes can perform adequately as insulation materials with any or little manipulation. The fabrication process should be improved in order to reduce the density of the mixtures and therefore their thermal conductivity.

### Acknowledgments

The authors would like to thank the Catalan Government for funding and for the quality accreditation given to the research group GICITED (2014 SGR 1298). M.P also thanks finance support under a grant FI-DGR.

### References

- [1] Cuchí, A; Sweatman, P. (2011). Informe GTR. Una visión-país para el sector de la edificación en España. Hoja de ruta para un nuevo sector de la vivienda.
- [2] Latif, E. et al. (2010). Potential for research on hemp insulation in the UK construction sector, pp.143–150.
- [3] Cuchí, A; Sweatman, P. (2012). Informe GTR 2012. Una visión-país para el sector de la edificación en España. Plan de acción para el nuevo sector de la vivienda.
- [4] Mangesh V. et al. (2013) Application of agro-waste for sustainable construction materials: A review; Construction and Building Materials 38, 872–878.
- [5] Sobral H. S. (ed.) (1990). Vegetable plants and their fibres as building materials. Chapman and Hall, London
- [6] Halvarsson, et al. (2010). Wheat straw as raw material for manufacture of medium density fibreboard (MDF). BioResources 2010, 5(2), 1215-1231.
- [7] Wall, K. et al. (2012). Development and testing of a prototype straw bale house. Proceedings of the Institution of Civil Engineers. Construction Materials 165, pp 377–384
- [8] United States Patent Office (1901) De Long, J. Insulating material. Specification forming part of Letter Patent N° 687,131.
- [9] Pinto, J. et al. (2012). Characterization of corn cob as a possible raw building material. Construction and Building Materials, 34, pp.28–33.
- [10] Pinto, J. et al. (2012). Corn cob lightweight concrete for non-structural applications. Construction and Building Materials, 34, pp.346–351.
- [11] Dowling, A. Mathias, J. A. (2007). Experimental determination of the insulating ability of corn by-products. Journal of Sustainable Agriculture, 30:2, 15-27



- [12] Wang, D. Sun, X.S., (2002). Low density particleboard from wheat straw and corn pith. *Industrial Crops and Products*, 15(1), pp.43–50.
- [13] Molinar-Higuera, S. E. et al. (2010). Evaluación térmica de un material natural atípico para uso como aislante térmico en construcciones civiles. *INTEC*, Vol 1, No 1.
- [14] Vejelienė, J. et al. (2011) Development of thermal insulation from local agricultural waste. *Environmental engineering*. 8th International Conference, May 19-20, Vilnius, Lithuania.
- [15] Cadena, C. G. Bula, A. J. (2002). Estudio de la variación en la conductividad térmica de la cascarilla de arroz aglomerada con fibras vegetales. *Ingeniería y desarrollo*, Universidad del Norte Barranquilla, N° 12, pp 1-9.
- [16] Anger, R. Fontaine, L. (2011). Interactions argiles/biopolymers: Patrimoine architectural en terre et stabilisants naturels d'origine animale et végétale. *Projet PaTerre+*, PNRCC.
- [17] Galán-Marín, C. et al. (2010). Clay-based composite stabilized with natural polymer and fibre. *Construction and Building Materials*, 24(8), pp.1462–1468.
- [18] F. Collet et al. (2011). *Construction and Building Materials* 25 1079–1085
- [19] Korjenic Azra, et al. (2011) Development and performance evaluation of natural thermal insulation materials composed of renewable resources. *Energy and Buildings* 43:2518–23.
- [20] Callum A. et al. (2009). The Water Vapor Sorption Behavior of Natural Fibers. *Journal of Applied Polymer Science* Vol. 112, 1524–1537.
- [21] Palumbo, M. et al. (preprint 2014) Availability of crop-wastes in Spain: new raw materials for NFI
- [22] Palumbo, M. et al. (preprint 2014) Characterization of crop-wastes as raw materials for NFI
- [23] Fahmy, Y. et al. (2010) Plant proteins as binders in cellulosic paper composites. *International journal of biological macromolecules*, 47(1), pp.82–5.
- [24] Zalbidea, A. San Marín, A. (2012) El uso de la pintura a la cal: ventajas e inconvenientes de su aplicación (con aditivos como la caseína y el aceite) sobre morteros tradicionales. *ARCHÉ* num 6-7.
- [25] Gubianas, N. et al. (2014) Anàlisis de formulacions per aïllaments tèrmics elaborats amb residus vegetals i aglomerants orgànics.
- [26] Jirickova M, Cerny R. (2006) Effect of hydrophilic admixture on moisture and heat transport and storage parameters of mineral wool. *Construct Build Mater*; 20:425–34.
- [27] Ilkka Valovirta et al. (2004) Permeability and Thermal Conductivity as a function of Temperature and Relative Humidity; *Buildings* IX 1-16, ASHRAE.
- [28] Pfundstein, M. et al. (2007). *Insulation Materials. Principles, Materials, Applications. Detail Practice*. Ed. Architektur-Dokumentation GMBh & CO. KG, Munich.



## UK experience of the use of timber as a low embodied carbon structural material

### Speakers:

Soulti, E<sup>1</sup>; Moncaster, A<sup>2</sup>

<sup>1</sup> University of Cambridge, Cambridge, United Kingdom

<sup>2</sup> University of Cambridge, Cambridge, United Kingdom

**Abstract:** *As buildings become more energy efficient in their operation, embodied energy and carbon become increasingly important. However, there is limited information to allow accurate comparisons of products. Moreover, construction projects are quite complex, not only regarding environmental issues, but also processes and stakeholders. The study of timber as a structural material in the UK is used in this paper to illustrate these factors. The paper brings together five studies and it considers the decisions and processes affecting the use of timber. The EE and EC of timber throughout its lifecycle are identified, including a discussion of assumptions. The impact of various decisions is assessed and the paper concludes by identifying technical and social factors for the focus of policy makers and the industry.*

### **Timber, embodied energy, embodied carbon, building structure**

#### **Introduction**

As buildings' operational energy (OE) performance improves, embodied energy (EE) and embodied carbon (EC) become increasingly important. Research focusing on the comparison of OE and EE [1] shows that for conventional buildings, EE represents between 2% and 38% of the energy use over their lifetime periods. This becomes 9% to 46% for low-energy buildings and even 100% for 'zero carbon' ones. Hence, accounting for embodied burdens in construction practices is crucial. However, the lack of information, the loyalty to conventional construction methods and the decision-making processes prevent this change from occurring.

The aim of this paper is to expand on and clarify information regarding the use of timber as a structural material in the UK. This includes an analysis of the EE and EC of timber versus steel and concrete, with details of its End-of-Life (EoL) scenarios and a discussion of the potential advantages of timber construction. Finally, barriers to its wider use are investigated.

This paper is structured as follows. The second section provides contextual information and the third one describes the research methodology. The fourth and fifth sections identify the most carbon intensive lifecycle stages and building elements. The sixth section describes the advantages of timber and the seventh explains factors affecting its use. The final section emphasises the uncertainties of the research, summarising findings for different stakeholders.

#### **Background**

Buildings' construction and use are significant contributors to carbon emissions, being liable for almost 25% of worldwide emissions [2]. A further 5% is attributed to cement manufacture





[3]. Therefore, there is extensive research on the comparison of timber and lightweight construction versus concrete and heavyweight construction. Monahan [4] explains that brick and concrete construction is of higher EE compared to timber. Moreover, research in New Zealand [5] concluded that significant reductions in EC would result from a shift from steel and concrete to timber, provided that timber is sustainably produced.

The European Standard TC350 provides a calculation method for the whole-life performance of buildings, focusing on cradle-to-grave, with an optional stage beyond this. Cradle-to-grave includes: product, construction process (including transport and construction), use and EoL [6]. However, the materials' country of origin and databases used can have a significant impact, while systems boundaries can be debatable. For example, defining the lifespan of the building as 25 or as 50 years can increase the initial EE by 59% or 148% respectively [7].

The calculation of EE and EC for timber construction, poses two very challenging issues: carbon sequestration and EoL scenarios. There are controversial opinions on including carbon sequestration for EC calculations of timber [8, 9]. Weight [9] considers the provenance of timber as the most important influence in sequestration and EC calculation for timber. Regarding EoL, Symons [8] addresses recycling, incineration and landfill. When recycling, the carbon 'credit' gained during sequestration remains intact. On the other hand, when timber is incinerated with full combustion, carbon of the same amount originally sequestered, is released into the atmosphere. The energy stored in the timber is released and can be recovered, hence an energy credit can be taken. Finally, in landfill, the carbon stored in timber is released as CO<sub>2</sub> or methane. The EoL scenarios depend on the country and landfill use; thus the comparison of various studies in different geographic contexts, is very challenging.

### Methodology

As explained above, boundaries and lifecycle stages may vary between different studies. This paper discusses the boundaries and assumptions for EE and EC, focusing on timber compared to conventional materials. Structural timber use is currently limited in the UK, unlike concrete and steel. The paper is primarily based on studies conducted by five groups of researchers:

- Darby et al.[10]: an assessment of timber's EC and storage capacity as a structural material for a new building. The research focuses on Cross Laminated Timber (CLT) used for a multi-storey building, carbon storage during the building's life and the impact of EoL scenarios on EC. CLT is solid timber panels manufactured off site, with very low waste and a very quick erection time.
- Gavotsis [11]: OE and EE analysis of a new school building, using prefabricated timber beams. The study includes all stages of building lifespan, from product to EoL.
- Monahan [4]: timber frame versus conventional masonry at a housing development, focusing on EE and EC of the product and the construction stages.
- Moncaster [12]: decision-making and stakeholders' influence on the use of timber as a structural material for two school buildings.



- Vukotic et al. [13]: timber versus steel: an assessment of building structures' EE. The study includes all stages of a building lifespan, from product to EoL.

### **Carbon intensive stages of buildings' lifecycle**

As Gavotsis [11] describes, research has identified the product stage as being responsible for the greatest percentage of EE and EC in buildings. In his study, the product and refurbishment stages contribute to EC with 50% and 31% respectively. Transport, construction and EoL are only liable for 8%, 7% and 4% respectively. Within this 50%, minerals come first, followed by plastics, metals and timber. Monahan [4] finds that for the timber frame scenario, 82% of the EC is due to the materials, excluding waste. The rest is due to transport and construction. Vukotic et al.[13] also calculate that for both the steel and the timber frame options, the product stage is the most significant, with 90% and 77% of total EC respectively. Different calculation methods, with differing temporal and material boundaries, highly influence the outcome, therefore the comparison of different cases should be made with caution.

Monahan [4] identifies waste as an important contributor to EE; the construction industry is responsible for more than one third of total waste in the UK; half of this is recycled or reused. She explains that 10 to 15% of materials brought on site are exported as waste, due to over-ordering. A potential solution is off site manufacturing, which produces lower waste than on site construction [14]. The Waste Resources and Action Programme estimates that the waste reduction through substituting traditional with prefabricated systems is 20% to 40% [14].

Finally, in the carbon sequestration calculations by Darby et al. [10], it has been demonstrated that if 100% carbon sequestration is assumed, the EC of the CLT frame building is 1006 tCO<sub>2e</sub> lower than the RC frame equivalent, approximately equal to the carbon footprint of all building occupants for a year. If no sequestration is assumed, the CLT frame building is liable for 186 tCO<sub>2e</sub> more EC than the RC. However, since the softwood spruce timber used for the CLT frame is produced usually on a 40 to 60 year period rotation [15] and is sourced from sustainably managed forests, Darby [10] suggests assuming 100% sequestration.

In conclusion, material production is the most important stage in a building's lifecycle and it is also likely the stage that provides a very high potential to reduce EE and EC.

### **Carbon intensive building elements and materials**

Since the product stage is so significant in a building's lifecycle, it is worth comparing building elements and materials, to identify the potential of various strategies in reducing EC.

Gavotsis [11] identifies the superstructure as responsible for half the EC, followed by the ground floor slab and the foundations. In his study, concrete is the principal material for the foundation and slab, while the superstructure is mainly made of timber.

Monahan [4] compares two distinct building scenarios in her research:

- A timber frame structure assembled off site, with timber façade: the substructure, foundations, first floor and roof are constructed using concrete.



- A conventional masonry construction: the materials are heavier than those in the previous scenario and thus an increased substructure was needed.

The latter construction method increases EC by 34% and EE by 26% compared to the former one. Both Monahan [4] and Gavotsis [11] in their timber frame buildings calculate that the substructure, foundations and ground floor slab together are responsible for half the EC. In Monahan's conventional masonry construction, this percentage drops to 37%, due to more carbon intensive materials being used in other components [4]. For both scenarios of this study, the principle material contributor to EC is minerals<sup>1</sup>, mainly concrete. In the timber frame scenario, the majority of minerals are used for the substructure and foundations. These elements are responsible for 45% of materials' emissions, with concrete accounting for 81% of minerals' EC. In the conventional masonry scenario, materials account for 86% of the total EC, with minerals being liable for 77% of this [4].

In the research by Vukotic et al. [13], it is assumed that both timber and steel scenarios require identical concrete foundations and slab, hence resulting in very similar EE; in the timber scenario, materials account for 79% of EE, as opposed to 88% in the steel scenario.

The analysis in this section suggested that building elements where materials with high embodied intensity such as concrete are typically used, are worth improving, by integrating the use of less carbon intensive materials, such as timber. Monahan cites the case of alternative wall elements of different weight, hence requiring different load bearing structures [4]. This could further increase the carbon benefits of timber; as a lighter wall element, it requires less materials for the building's concrete substructure and foundations.

### **Advantages of timber construction**

The previous two sections identified the advantages of timber versus steel and concrete in terms of EE and EC. However, timber can potentially involve more aspects that are positive. The use of CLT is related to dimensional stability; good fire resistance; easiness of achieving airtight construction; good insulation properties [10]. Moreover, according to Darby et al. [10], CLT construction is quicker, with an erection time of 10 weeks for a multi-storey building, versus 14 weeks for the reinforced concrete (RC) construction of the same building.

Furthermore, in one of the projects described by Moncaster [12], CLT construction presents numerous advantages for the contractor, namely improved health and safety on site, decreased cost due to reduced construction time, improved cleanliness, quietness and accessibility due to absence of scaffolding. Finally, the developer may use the decreased EE of timber to their advantage, as it happened in Bridport House [10], where the planning authorities agreed to reduce the requirement for on site renewable energy by 10% [16].

### **Factors influencing the choice of timber as a structural material**

The sections above demonstrated the advantages of timber replacing steel or concrete as a structural material. However, its use in the UK is still very limited.

<sup>1</sup> Minerals in this study included cement, gravel, sand and concrete products.



Lifecycle assessment is a challenging process, due to the numerous parameters involved. One of the messages of the Carbon Week 2014 was the need to improve consistency and transparency [17]. The lack of these characteristics impedes the wider adoption of timber.

This section analyses the decision-making regarding sustainability in school buildings described by Moncaster [12]. It identifies barriers and incentives to the use of timber, with a focus on politics and attitudes towards sustainability by professionals and stakeholders.

The involvement of stakeholders in decision making regarding sustainability can be crucial. Projects are usually shaped through the requirements of clients, but their decisions are strongly influenced by the information provided by the design team. While ‘sustainability’ is often expressed as a priority, it is open to interpretation. Expertise in sustainability is a powerful opportunity at the moment; hence many professionals promote their area as ‘sustainable’ [12]. In one of the schools [12], there was a disagreement on the interpretation of sustainability and each professional had reasons to suggest different strategies. Services engineers considered renewables as a synonym of sustainability, while the structural engineer highlighted the importance of EC. CLT was used as a structural material, partly due to the structural engineer who produced calculations on the EC of timber and concrete. On the other hand, the quantity surveyor, was against timber, due to the difficulty of costing an innovative at the time structural material and a fear that his expertise might be doubted.

The sustainability assessment and the tools used are also important. In the case analysed above, both the structural engineer and the architect, felt that BREEAM was limited as a tool, since it did not support the use of structural timber [12]. In most cases, tools have a significant influence, by including, excluding or interpreting options. According to Guy and Shove ‘design tools do not simply translate between the languages of science and practice. Like it or not, they have hidden agendas and qualities of their own’ [18] (quoted in Moncaster [12]).

Finally, policy is a factor that can hinder or promote the use of specific materials. Moncaster [12] suggests that omitting EC from the definition of ‘zero carbon’ reflects the priority of the politicians to encourage work in construction. Industry experts consulted also reflect these priorities; key policy documents which led to the current UK Building Regulations were based on reports by Barker [19] and Callcutt [20] and responded to powerful lobbies such as the cement and concrete industries, rather than reduced carbon [12]. Hence, the choice to use a material on a broader basis, is not only a project-specific decision; political priorities and policies can be included in this decision-making process as equally important elements.

### **Discussion and conclusions**

It has been demonstrated that the use of structural timber decreases EE and EC compared to conventional materials. Concrete typically used for structural elements of buildings has been proven to be a major contributor in terms of EE and EC. Therefore, its replacement by timber can have an effect on EC reduction in buildings; this is an important finding, enabling designers to make more informed decisions. Moreover, timber is a clean, safe material, improving the construction times and its use can involve multiple advantages for contractors.



However, the multitude of parameters and assumptions involved complicates the analysis and comparison between materials and construction methods. Besides, there is an inherent difficulty in predicting the EoL of products. As Vukotic et al. [13] describe, EoL refers to a projection of the future; with practices and technologies likely to change, it is very hard to identify the demolition, disposal and recovery practices so much time in advance.

Furthermore, it is worth studying in detail the effect that materials have, not only on EE as described in the previous sections, but also on OE. As Monahan describes [4], concrete has higher thermal mass and can thus assist in reducing heating and cooling loads, which does not happen in the case of timber; nevertheless, this is not easily quantifiable. Future work may involve the application of timber, steel and concrete as alternative structural materials on a specific building, in order to assess both OE and EE and to compare additional quantifiable or non-quantifiable benefits of each construction method.

Despite the advantages of structural timber, it is not currently broadly used in the UK. Decision-making processes, the professionals' expertise in sustainability, new materials and embodied burdens, as well as lack of knowledge, hinder the broader use of timber. This paper contributes to the knowledge around timber construction in the UK and informs the industry on its potential and on relevant technical or socio-political barriers. Moreover, given the significance of reducing carbon emissions, it is crucial to inform policy makers on the use of non-conventional materials. The description of timber's share in EE, its EoL scenarios and finally the factors complicating its use in the UK, can be valuable for policy makers and the industry, contributing to the promotion of alternative construction methods.

### Acknowledgements

The authors would like to thank SIG Energy Management for their support of this research.

### References

- [1] Sartori, I. and Hestnes, A.G. (2007) Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy Build.*, vol. 39, no. 3, pp. 249–257.
- [2] IPCC (2007) Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
- [3] Worrell, E., Price, L., Martin, N., Hendriks, C. and Meida, L.O. (2001) Carbon Dioxide Emissions from the Global Cement Industry. *Annu. Rev. Energy Environ.*, vol. 26, pp. 303–329.
- [4] Monahan, J. (2013) Housing and carbon reduction: Can mainstream 'eco-housing' deliver on its low carbon promises? University of East Anglia.
- [5] Buchanan, A.H. and Honey, B.G. (1994) Energy and carbon dioxide implications of building construction. *Energy Build.*, vol. 20, no. 3, pp. 205–217.
- [6] RICS (2012) Methodology to calculate embodied carbon of materials - RICS Information Paper. London.

**Comentario [ES1]:** Replace references with the conference format and make sure they don't change after saving the document etc.





- [7] Cole, R.J. and Kernan, P.C. (1996) Life-cycle energy use in office buildings. *Build. Environ.*, vol. 31, no. 4, pp. 307–317.
- [8] Symons, K.E., Moncaster, A.M. and Symons, D. (2013) An Application of the CEN/TC350 standards to an Energy and Carbon LCA of timber used in construction, and the effect of end-of-life scenarios, in Australian Life Cycle Assessment Society conference.
- [9] Weight, D.H. (2011) Embodied through-life carbon dioxide equivalent assessment for timber products, *Proceedings of the ICE - Energy*, vol. 164, no. 4, pp. 167–182.
- [10] Darby, H.J., Elmualim, A.A. and Kelly, F. (2013) A case study to investigate the life cycle carbon emissions and carbon storage capacity of a cross laminated timber, multi-storey residential building, in *Proceedings of the World Sustainable Building*.
- [11] Gavotsis, E. (2013) The way forward for practical measurement and reduction of embodied energy and carbon in UK buildings: The case study of St Faith's School. University of Cambridge.
- [12] Moncaster, A.M. (2012) Constructing sustainability: connecting the social and the technical in a case study of school building projects. University of East Anglia.
- [13] Vukotic, L., Fenner, R.A. and Symons, K. (2010) Assessing embodied energy of building structural elements. *Proc. ICE-Engineering Sustain.*, vol. 163, no. 3, pp. 147–158.
- [14] Waste Resources and Action Programme (2008) Waste minimisation through offsite timber frame construction. Banbury.
- [15] Moore, J. (2011) Wood properties and uses of Sitka spruce in Britain. Edinburgh.
- [16] Miller, G. (2012) Cross-laminated timber: the sky's the limit. [Online]. Available: <http://www.theguardian.com/sustainable-business/cross-laminated-timber-built-environment?newsfeed=true>. [Accessed: 14-Feb-2014].
- [17] UK Green Building Council (2014) Summary report: Embodied Carbon Week - Seeing the whole picture, London, UK.
- [18] Guy, S. and Shove, E. (2000) *A sociology of energy, buildings and the environment: constructing knowledge, defining practice*. New York: Routledge Research Global Environmental Change.
- [19] Barker, K. (2004) *Review of Housing Supply: Delivering Stability: Securing our Future Housing Needs*. Chaired by Kate Barker on behalf of the Office of the Deputy Prime Minister, London.
- [20] Department for Communities and Local Government (2007) *The Callcutt Review of Housebuilding Delivery*, Rotherham.



## Challenges of District Cooling System (DCS) Implementation in Hong Kong

### Authors:

Lo, Alvin<sup>1</sup>; Lau, Barry<sup>2</sup>; Cheng, Vincent<sup>3</sup>; Cheung, Patrick<sup>4</sup>

<sup>1</sup> Arup, Hong Kong, China

<sup>2</sup> Arup, Hong Kong, China

<sup>3</sup> Arup, Hong Kong, China

<sup>3</sup> Electrical & Mechanical Services Department, HKSAR Government, Hong Kong, China

**Abstract:** *The District Cooling System (DCS) is one of the most important green features to materialise the sustainability vision of HKSAR Government. Its application was found in the Kai Tak Development (KTD) and other planned new developments in Hong Kong. By applying the DCS, benefits can be realised through cooling load sharing amongst the diversified cooling requirements, reduced standby capacity and spatial requirements. Apart from reducing the overall plant space, the operational cost, maintenance cost and energy efficiency can also be improved substantially and therefore be more cost-effective throughout the building life-cycle. Yet, there are many challenges on implementing the system. Issues on land use, planning, design, environmental, institutional and regulatory arrangement are substantial. This paper will discuss some of these challenges and the possible solutions for the DCS installed in Hong Kong*

***District Cooling; District Energy; Energy Efficiency; Air-Conditioning; Sustainable Design; Low Carbon Planning***

### Introduction

The use of electricity for air-conditioning system in Hong Kong contributes 29% of our total electricity consumption [1]. Nowadays, providing comfortable indoor environmental conditions for the occupants of offices and other public spaces is a basic requirement. Energy efficiency of our air-conditioning system is therefore imperative on achieving the energy saving target of the society as a whole. Energy codes on controlling the design of air-conditioning and other building services systems are now in place in Hong Kong.

Amongst different energy-efficient systems, DCS is the most sustainable solution for the planning of a new district, in which chilled water can be distributed through a network of underground pipes from a large scale centralized chiller plant to multiple buildings. It is particularly suitable for developments with high-density or clusters of buildings, which minimizes the infrastructure required for the distribution of chilled water to buildings of different uses.

A successful DCS has to be planned and designed with enhanced system performance and economics in mind. This is done by optimizing the design of chilled water production and the associated distribution network, therefore enhancing the energy efficiency and financial viability. Based on the most recent experience of DCS systems in Kai Tak Development (KTD), it has a potential to save 20% to 35% energy as compared with traditional air-cooled



air-conditioning systems and water-cooled air-conditioning system. The users can also enjoy a better quality and reliability of services.

In addition to a better energy efficiency, there are other environmental and planning benefits by adopting DCS, such as:-

- Reduced water consumption
- Reduced carbon footprint
- Minimised noise and vibration impact
- Flexibility in building design
- Saving in plantroom space
- Reduced operating redundancy
- Enhanced system reliability

When developing the implementation strategy of a DCS, it is necessary to consider the business environments and constraints of providing cooling services to the district. In particular, the viability of the DCS service is highly susceptible to the specific project constraints including the urban and utility planning requirements, development programme and potential users and provider(s) etc. Cost model and financial analysis are essential to evaluate the potential of the DCS as a business in the market to compete with alternative cooling technology — i.e., that potential customers will connect to the DCS if it promises to be not more expensive than installing alternative cooling.

### **DCS systems at Kai Tak District**

The KTD DCS is the first of its kind innovative cooling method to be implemented in Hong Kong. It is one of the key initiatives of the 2008-09 Policy Address when the Government planned to implement the DCS to promote energy efficiency and conservation. KTD is a mixed development with a GFA of over 1.7 million m<sup>2</sup> of non-domestic air-conditioned area in the old Kai Tak Airport area. The development includes commercial offices & retail, government offices of various departments, transport infrastructure, community buildings, hotels and both public and private housings. The DCS will serve all the buildings of KTD, with the exception of domestic developments. The feasibility study, system design and implementation were commenced from year 2000 to realise this innovative and energy efficient system. By using seawater for heat rejection, there is further energy saving and also have more open spaces released to the public through removal of cooling towers. Figure 1 shows the masterplan of KTD DCS.



Figure 1: Masterplan of KTD DCS

The KTD DCS comprises two separate plants and associated chilled water distribution network and customer substations. The south DCS plant room, named South Plant is situated underground at the previous flight runway at Kai Tak serving the South Apron and Runway Boulevard of KTD. The plant adopts variable primary flow chilled water system with direct seawater cooled heat rejection method.

The north DCS plant room, named North Plant is situated at the northern end of Kai Shing Street and adjacent to Kwun Tong Bypass in KTD serving the North Apron. Same as the South plant, the chiller system is a variable primary flow with direct seawater cooled heat rejection arrangement. The main distribution chilled water pipe is a 3-pipe ring circuit direct buried underground.

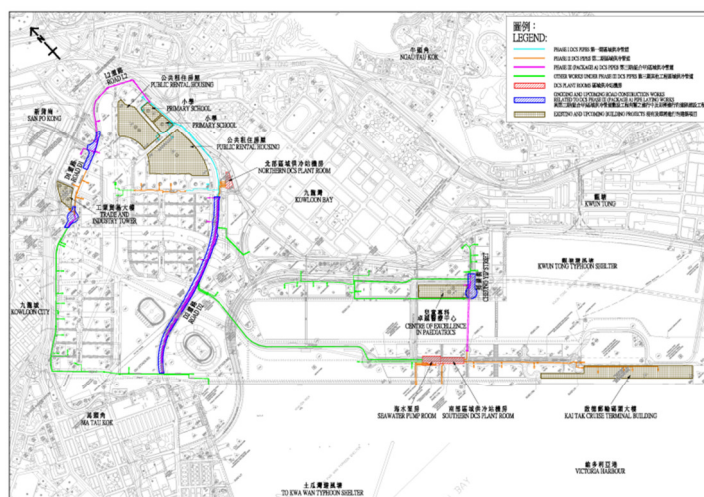


Figure 2 Phased implementation of KTD DCS

The DCS project is funded by The Government of the Hong Kong Special Administrative Region and is being implemented in three phases (Figure 2). Phase I works are mainly on pipe laying and Phase II works on construction of chiller plant rooms, seawater pump house, and other associated facilities were started in February and March 2011 respectively. Works in



these two phases are scheduled to tie in with the earliest development in KTD, including the Kai Tak Cruise Terminal and public housing estate. To serve the remaining developments of KTD, Phase III works on installation of additional electrical and mechanical equipment and extension of pipes commenced on July 2013.



*Figure 3: North Plant and chiller installation*

The South Plant commenced operation in February 2013, serving Kai Tak Cruise Terminal. And the North Plant also commenced operation in May 2013, serving the new developments at the North Apron area.

With a design capacity of 284MW, the KTD DCS will reduce electricity consumption by approximately 35% compared to conventional air-cooled system. The maximum annual saving of electricity is expected to be about 85 million kWh, equivalent to a reduction of 59,500 tonnes of carbon dioxide emissions from the development.

### **Challenges on DCS Implementation**

Despite the advantages of DCS experienced in KTD, full implementation of DCS in Hong Kong faces many challenges and makes it difficult to reach its full potential.

#### Site planning and interfacing issues

The sites for the construction of DCS plants and pipeworks are extensive and the construction will generally be carried out in phases extending over a long period. Inevitably there will be interfaces with other infrastructure, especially at the chilled water and condensing water pipeworks. Lot of interfacing issues is common and may happen even in green field site. An integrated planning approach is required to minimize its complication on construction and therefore the potential escalation on cost.

Whenever an interfacing issue is identified, coordination has to be conducted with concerned parties to deal with the constraints and to resolve the conflicts, preferably during the early scheme design stage.



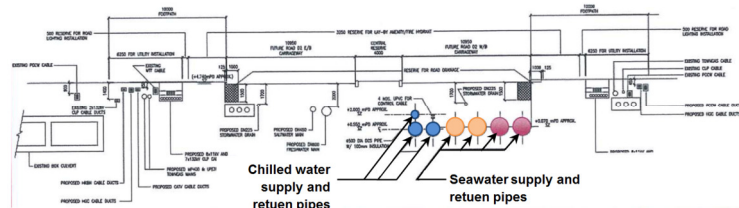


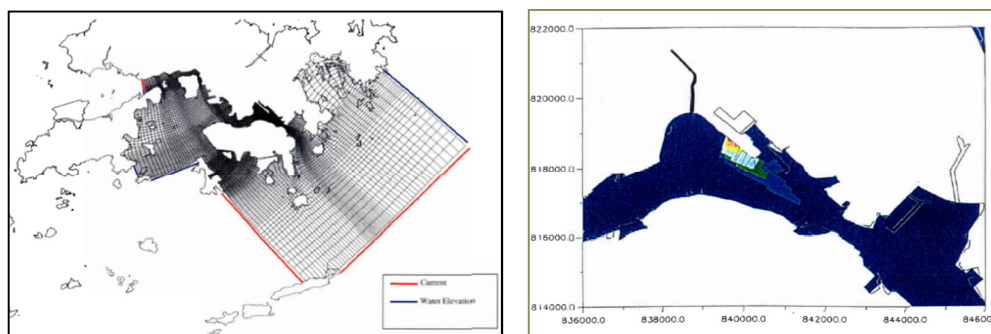
Figure 4: Typical arrangement DCS pipes along with other utility facilities on along a congested site.

### Discharge of condensing water

Direct seawater cooling method was adopted by the KTD DCS, implying that seawater will be drawn from the Victoria Harbour and discharge back to it for heat reject. An exercise for the approval of Environmental Impact Assessment (EIA) has conducted in the early planning stage. The water quality criteria (for temperature, biocides and residual chlorine) for cooling water discharges have been agreed with Environmental Protection Department (EPD). The Near field and far field numerical models were then be used to assess impacts of seawater intake for cooling and thermal effluent (seawater) discharge. Typically for cooling water discharges, a water temperature of 2°C above ambient should be achieved at the edge of the mixing zone. To prevent short-circuiting of the intake and discharge locations, intake water temperature should be less than 0.5°C above ambient.

The CORMIX model developed by USEPA was used for predicting near field thermal plume behaviour. The Cormix model provides information on the spread (plume width), dilution and trajectory of the thermal plume. Where necessary the boundary conditions of the near-field will be extracted from the far-field model. Different tidal conditions would also be taken into considerations. Far field modelling was carried out using the Delft3D suite of models. Detailed models for the Victoria Harbour, the Eastern Buffer, and Western Buffer Water Control Zones have been set up, calibrated, verified, were discussed and agreed with EPD.

Compliance with Water Quality Objectives has also been assessed based on the water quality modelling results. Statistical analyses of water quality, temperature changes, biocide concentration, residual chlorine etc, were conducted at representative indicator points in the zones of interest. Some of the indicator points were located at the same EPD routine monitoring stations to check for consistence with historical data. Based on modelling results, the distance separation needed between the intake and discharge locations were determined so as to prevent short-circuiting by cooling water discharge.

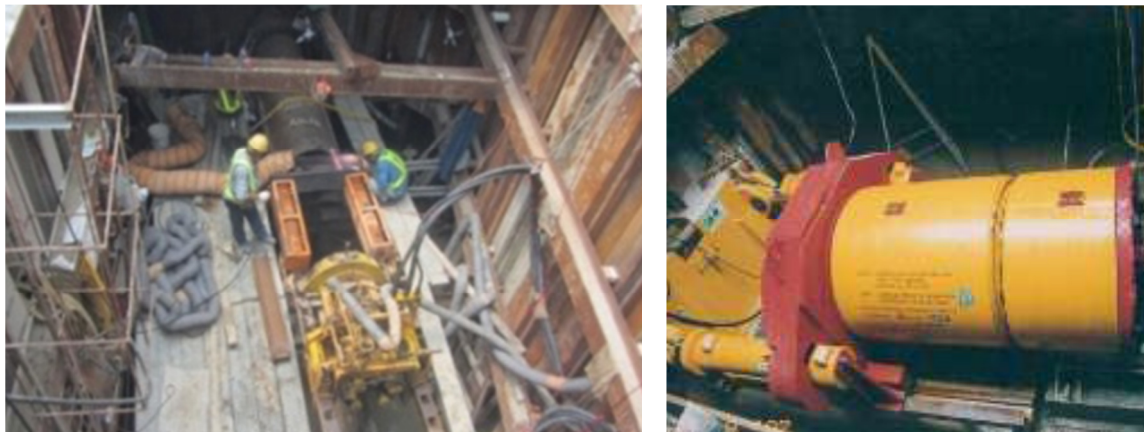


*Figure 5: Thermal model and water quality model for planning of seater intake and outfall location along the Victoria Harbour.*

### Construction challenges

For the pipe-laying works, both open trench method and trenchless excavation method were adopted. Trenchless excavation method was applied in some sections, where existing site constraints are prohibitively high for constructing any trench. This method can minimize the disturbance to the public.

Trenchless method by means of Tunnel Boring Machine (TBM) was used. It has the advantages of giving limited disturbance to the surroundings and producing a smooth tunnel surface. However, in using the TBM for constructing the DCS pipes, there are limitations on curve radius and generally the maximum turning angle of bored tunnel is 5 degrees. There is also a requirement of a minimum site area for the jacking pit and receiving pit which depend on the size of drill head. In addition, sufficient working space for sediment/slurry treatment tank and TBM operation and control room should also be required.



*Figure 6: Pipe Jacking method for DCS pipelaying at complex sites.*

### Pipe Insulation

As the DCS pipework involved an extensive network of underground pipework, the amount of heat gain in the pipework has a significant impact to the energy efficiency and cost effective of the system. The heat gain of the underground pipework system depends on the type, thickness and thermal properties of insulation, pipe diameter, chilled water temperature and ambient condition. In order to obtain an optimum thickness of the insulation, the heat gain calculation against the cost with different thickness of insulation has been carried out and concluded that factory-prefabricated insulation by using polyurethane with 65mm thickness has been adopted. All necessary components are prefabricated at the factory which can not only control the workmanship and quality, but also minimize the installation time at the site.

### Leakage Detection System

As most of the pipeworks are direct buried, monitoring system is therefore required to check the pipework performance and allowed early warning if it has any leakage. Water leakage detection system installed to monitor the DCS distribution network so that the DCS service provider will carry out remedial action once leakage is found along the pipeline. This can provide early warning to the service provider and also provide systematic monitoring to the pipework performance. The leakage detection system is addressable so that it can identify the leakage within a certain length and leak detection sensitivity level must be able to be adjusted at site to suit the condition. Sensing cables shall be installed in factory together with pre-insulated pipework to maintain good quality

### Testing and Commissioning

For the system as complicated as the DCS, Testing and Commissioning (T&C) plays a pivotal role on its normal operation and energy saving in long-term. Systematic approach is required to ensure all the components are function at its designed performance and the entire system at its maximum efficiency. Three level of checking were proposed for the T&C plan:-

- 1) **Components and Plant Level** - Specifications for sub-system components specifies quality requirements, performance requirements and life time requirements, which allows for review of fabrication and factory testing of components. Typically, a plant was inspected and tested after installation on site in order to secure that no damage has occurred during transport. For major equipment such as chiller, FAT test was carried out before delivery to ensure the performance is satisfactory.
- 2) **Sub-systems & DCS Pipework Level** - After delivery / installation of components and subsystems, such as chiller, pump, pipework etc, close supervision was enforced by experienced engineer and subsequently tested for joint functionality in accordance with specifications.



*Figure 7: Non-destructive Test for field welds on DCS pipework*



- 3) **Overall System Level** – This is the functional Testing of the entire DCS System. The tests shall demonstrate the compliance of the Contractor's works with the design requirements. The test demonstrates the ability of the DCS System to operate at the optimum efficiency. Verification of system redundancy including failure of equipment and burst of sectional pipeline shall be included.



Figure 9: Functional test of DCS system (a) Embedded water leakage detection cable in direct laying DCS pipework; b) Hydraulic pressure Test of DCS Pipework

## Conclusion

DCS delivers significant benefits both in terms of environmental, comfort, operational efficiency, energy conservation, flexibility in planning and superior system reliability. The recent KTD DCS has demonstrated the commitment of the Government on implementing the concept in Hong Kong. Yet, the entire planning, design, construction and operation process are not without difficulties. Integrated designs as well as innovation in construction technology of DCS are the key to success. In long run, DCS (if widely adopted in Hong Kong) could play an essential role in de-carbonizing Hong Kong and promoting more innovations to our construction industry.

## References

- [1] Electrical and Mechanical Services Department (2012). Hong Kong Energy End-Use Data 2012, Hong Kong
- [2] Arup (2003). *Reports for Implementation Study for a District Cooling System at South East Kowloon Development*. Hong Kong
- [3] Arup (2007). *Initial Engineering Design and Contract Formulation for Kai Tak Development District Cooling System – Investigation*. Hong Kong
- [4] EMSD, *Design-Build-Operate a District Cooling System (Phase II Works) at Kai Tak Development*. Hong Kong



- [4] Lo, S.K. et al. (2011). Engineering Design for Power Supply to District Cooling System, *The 29<sup>th</sup> Annual Symposium of The Hong Kong Institution of Engineers – Electrical Division*. Hong Kong
- [5] International District Energy Association (2008). *District Cooling Best Practice Guide First Edition*. USA
- [6] International Energy Agency, 2004. *District Heating and Cooling Connection Handbook*. France
- [7] ASHRAE, 2013. *District Cooling Guide*. USA



## **Analysis, valuation and opportunity of energy intervention in historic downtowns of European cities. The “Ensanche Cortazar” of San Sebastian**

### **Speakers:**

Uranga, E. J.; Etxepare, L.

Departamento de Arquitectura - Universidad del País Vasco/Euskal Herriko Unibertsitatea.  
Donostia/San Sebastián, Spain.

**Abstract:** *New Spanish regulation, derived from the current European Directive, indicates that some minimum energy requirements must be applied to any building that is reformed. This means that the building stock of our historic downtowns faces a dilemma: either it must be systematically protected so that it is exempt from the application of the regulation, or if any reform is carried out on these buildings it must satisfy the specified energy requirements. The latter is the way forward to be able to reduce the energy consumption of the building stock, and energy intervention is already a reality in much of the built heritage. This study analyses a significant case of 19<sup>th</sup> century expansion districts: the Ensanche Cortazar of San Sebastian. Studying the energy performance of the residential building models that comprise it and intervening in their architecture serve to go further into the research of energy rehabilitation of our historic downtowns.*

**Keywords:** *Energy, Intervention, Historic, Ensanche Cortazar, San Sebastian.*

### **1. Introduction.**

Faced with the great challenge of having to reach the objectives laid down by the EU in terms of considerably reducing energy consumption in buildings and increasing their energy efficiency [1], we find that the energy rehabilitation of historic downtowns plays an important role in achieving these objectives [2]. Newly constructed buildings incorporate some baseline characteristics that guarantee reduced energy consumption [3]. But, the majority of the building stock is comprised of buildings constructed prior to the application of the energy efficiency regulation. Of the 10 million buildings that exist in Spain, more than 85% were built before 2000 [4]. It is in these buildings where we will have to take action if we really want to minimise the energy consumption of the building stock. A growth model was established in the 19<sup>th</sup> century expansion districts, which was repeated in many places throughout Europe. It is now, when energy intervention is extensively required in these downtowns, when we must take firm action, but, at the same time, we must not forget the urban, architectonic and constructive values that are typical of the historic city. Based on this need to intervene, we propose an intervention solution that assesses both the energy aspects and the preservation of the built heritage.

### **2. The « Ensanche Cortazar » and other 19<sup>th</sup> Century expansion districts.**

The industrialisation in Europe, a process that began in the 18<sup>th</sup> century and continued throughout the 19<sup>th</sup> century, was undoubtedly suffered the most in the cities. The large

European cities adopted two growth paths: the inner reform of the city and the new expansion in the form of a district. The first path consisted in acting upon the previously existing urban fabric, opening up new roads, infrastructures, spaces and facilities; this is the case of Paris under the mandate of Napoleon III and the management of Haussman, the prefect. The second, the path of the expansion district for the new populations, was started in Barcelona, thanks to the expansion project of Ildefonso Cerdà (1859), whose implementation and extension was developed throughout more than one century [5]. The influence of the new way of constructing the city proposed by Cerdà came swiftly. Shortly afterwards, the development of the Castro Plan in Madrid started (1860) and also very early on, the Ensanche Cortázar (1864), in San Sebastian. In all of them, a type of urban development was carried out, which resulted in a very specific building model: the closed block with common courtyard and small inner courtyard in each one of the building plots.

*Figure 1. Façades of nineteenth-century buildings in Paris, Barcelona and San Sebastian. Source: Original photographs taken by the authors.*

### 3. Urban planning and building construction of the “Ensanche Cortazar”.

After the demolition of the walls of San Sebastian that had been authorised by a Royal Order of the Government (1863), a competition was called for the city’s expansion project. The winning project was presented by Antonio Cortázar [6], who proposed the expansion of the city by means an orthogonal grid comprised of residential blocks, of 85x56 metres in the first phase and 56x56 in the second, limited by the old city, the Urumea River and the sea. The older buildings, corresponding to the first stage of the Cortazar expansion district and built near the Boulevard, are approximately 150 years old. The age of the other buildings gets gradually less the further away they are from the Boulevard, the youngest ones being located to the south and west. The half century that separates the construction of the former and the construction of the latter is reflected in the diversity of architectonic styles that comprise their main façades, but not so in the construction system. This expansion district has reached our days with a considerable degree of integrity. Of the 560 buildings that make up the ensemble, about 400 buildings are original.



Figure 2. "General map of the city and port of San Sebastian with the expansion for the new population". Map presented for the competition of the expansion district of the City. Source: Municipal Archive of San Sebastian.

#### 4. Energy and construction characteristics of the buildings.

The residential closed block model with common courtyard a priori presents good performance from the energy viewpoint. In the plots of land between the separation walls there are only two outer façades, the main one and the rear one that gives onto the courtyard of the block. Beside these façades only the roof is in contact with the outside. The sunlight is similar both on the main façade and on the rear one, as the inner dimension of the courtyard is usually similar to the width of the street. Obtaining more or less sunlight will depend on the orientation of the plot of land. The openings do not represent a large percentage of the total of these outer façades, no more than 30%. The walls that are in contact with the outside are solid walls with great thermal inertia, so they help obtain a better energy performance despite not having thermal insulation [7]. The bay window is an element that is added to the façade which, when the orientation is adequate, provides solar gains in winter, but in no case takes anything away from it, as behind the window bay there is an opening in the façade with the same carpentry as in the rest of the building. The roof, if the attic is inhabited, is the element that may cause more or less thermal gains and losses, due to the fact that it has no type of thermal insulation. If this were an uninhabited ventilated chamber, the fact that it is not insulated has no direct effect. The construction elements and the transmittance values of the outer envelope of the majority of these buildings are very similar. The organisation of the inner structure is normally all carried out in beech wood, based on transverse bays with a row of posts with between 2.5 and 4 m span. The top slabs are made with small wooden beams and board, as well as the roof structure, manufactured with wooden joists. The inner courtyard is situated in the centre bay, next to the separation wall, and is erected with solid brick one-foot walls. Sometimes, this courtyard is shared by two adjacent plots of land. The façade is made with sandstone ashlar work, and it is 0.8 m thick on the ground floor and 0.4 on the top floor. The façades have 1.10 x 2.50 metres openings and cantilever balconies of less than 50 cm. The rear façade is made of limestone masonry, 0.8 metres thick on the ground floor and 0.5 on the top floor, and it has similar windows to those of the main façade. The party walls are similar to the rear façade and they consist of one single wall shared by the two adjacent properties so they have a greater thickness.

With regards to the installation systems, although the heat was originally produced by economical cookers, reinforced at the most by a brazier, the analysis of the building model

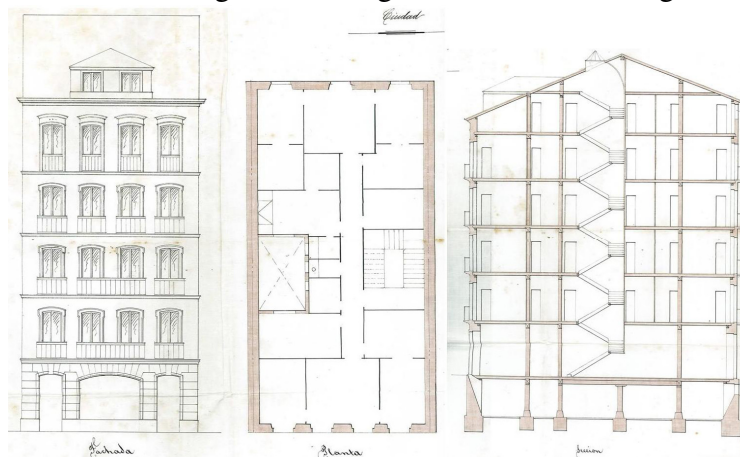
Vertical opaque enclosures					Horizontal opaque enclosure	
Main façade	Rear façade	Party walls	Inner courtyard enclosure		Top slabs between dwellings	Roof top slab

has been carried out considering a current heating system composed by individual city gas boiler, which is the most common in this historic downtown.

*Table 1. Transmittance values of the different enclosures of the building in state 0 or original state.*

### 5. Selection of the building model.

The building model, built in 1882 is located in number 5, Txurruka Street. It is a house situated between party walls, with one façade giving onto the street and the other onto the common courtyard. Its front measures 9.8 m and it has a depth of 20 m. It has a ground floor, four upper floors and an attic. The main façade faces south-west. There is one dwelling per floor, which goes from one end to the other. Despite some small differences in terms of façade fronts, type of roof and organisation of openings, the building analysed is representative of 71% of the original buildings that remain standing.



*Figure 3. Original plans of the building of Txurruka 5. Source: Municipal Archive of San Sebastian.*

### 6. The original energy performance of the building model.

To calculate the energy performance of both the original building and of the different interventions, the Lider-Calener\* program has been used, which is approved by the Ministry of Industry, Energy and Tourism of the Government of Spain. The values of the results are collected without bearing in mind if they comply or not with the current regulation (CTE DB-HE1 - Limitación de la demanda energética\*\*). These are; energy demand, in this case only heating (kWh/m<sup>2</sup>) as we are in climate zone C1\*\*\*; total CO<sub>2</sub> emissions (kgCO<sub>2</sub>/m<sup>2</sup>); total primary energy consumption (kWh/m<sup>2</sup>); and its energy classification based on CO<sub>2</sub> emissions. The data of the different components of the original thermal envelope have been entered together with a heating system and DHW of natural gas with individual combi-boiler for each one of the dwellings (5 dwellings).

With the results of this calculation, we obtain the original energy performance of the construction (State E0). The result is energy class E, with a heating demand of 128.3

kWh/m<sup>2</sup>, a total primary energy consumption of 170.2 kWh/m<sup>2</sup>, and total CO<sub>2</sub>/m<sup>2</sup> emissions of 37.0 kg. We can add that, although the results are very far from the current regulatory requirements, the energy performance is not bad when compared with other buildings prior to the entry into force of the first energy limitation standard [8].

*Figure 4. Modelling of the building of Txurruka 5 in the Lider-Calener program.*

## **7. The energy intervention on the building model.**

After calculating the current energy performance of the building, different solutions of the elements of the thermal envelope have been introduced to improve the energy efficiency. These elements have been introduced gradually to increase the resulting values of the improvement. Firstly, the carpentry on the façades (State E1) were modified, changing the original wooden ones with single glazing and highly permeable carpentries (Transmittance 5.33 W/m<sup>2</sup>K and Permeability >50 m<sup>3</sup>/hm<sup>2</sup> 100Pa) for new ones that satisfy the requirements of the new CTE DB-HE (Transmittance < 3.10 W/m<sup>2</sup>K and Permeability ≤ 27 m<sup>3</sup>/hm<sup>2</sup>). After changing the carpentry, the roof (State E2) was modified, with which the transmittance value changed from U=2.03 W/m<sup>2</sup>K to U=0.19 W/m<sup>2</sup>K. In this case, the typical parameters of the reference building included in the latest modification of the CTE DB-HE for Climate Zone C1 have been taken to satisfy and even improve the results. The third intervention introduced was to improve the inner courtyard enclosures (State E3). This is an element that is often considered as interior, despite the fact that it is in contact with the exterior. In this case, the value changed from U=2.92 W/m<sup>2</sup>K to U=0.22 W/m<sup>2</sup>K, trying to satisfy and also improve on the values established by the CTE DB-HE. Finally, in addition to the previous intervention, the transmittance of the façades was improved, including the main one and the block courtyard one (State E4). In this case, the values have improved from U=2.69 W/m<sup>2</sup>K for the main façade and U=1.91 W/m<sup>2</sup>K for the rear one, to U=0.70 W/m<sup>2</sup>K and U=0.64W/m<sup>2</sup>k, respectively. Considerable problems may be encountered with when executing this solution as if the intervention is carried out from the exterior, the façades in question are either catalogued, in which case the possible intervention is not feasible, or despite the fact that they are not catalogued, the intervention will have a substantial impact on its architectonic configuration. If the intervention is carried out from the inside, the inhabitable space of the dwelling will be reduced, so it will be difficult to apply if the owners do not give their consent. Even so, the calculation has been carried out to see what the energy efficiency would be. Apart from these calculations for intervention on existing elements, another hypothesis (State E5) has been conducted, whose aim is to reconstruct the current



building in form and volume, but with the enclosures of the outer envelope required by the current CTE DB-HE (building of reference). Thus, we will be able to compare, how far away we are from achieving this objective, comparing it with the results of our interventions.

## 8. Analysis of the results.

It is observed that, in general, as the improvements have been introduced, the building has undergone a reduction in energy demand and in energy consumption. By analysing each one of the interventions we can see that, with the change in carpentry (E1), we improve the values of the original building by up to 35%. In the second case (E2), it is observed that the values are humble better than intervention E1 (39%). This slight increase may be due to the fact that the attic is not inhabited. The results of the third intervention (E3) lead to an improvement of up to 46%. Finally, with the fourth solution (E4), an improvement of up to 57% the original state is attained. With respect to this final intervention, there is an improvement, a priori, of the transmittance and results, but the introduction of a thermal insulator may mean that we are losing the thermal inertia contribution of these elements. This is not the case of this study, but it would have to be verified if the use of this insulation improves the conditions or worsens them. Finally, taking the result of the calculation of the reconstructed building (E5), we find that we never manage to be below the maximum energy consumption values and maximum heating demand values required by the new CTE DB-HE. The resulting values are: primary energy consumption of 65.3 kWh/m<sup>2</sup> and heating demand of 42.3 kWh/m<sup>2</sup>, compared with 52 kWh/m<sup>2</sup> energy consumption and 22 kWh/m<sup>2</sup> heating demand for this building in Climate Zone C1. This means that, without modifying the energy installation system, we are still a long way from satisfying the new standard. On the other hand, if we compare the interventions proposed with these latter results of E5, the values are much closer to the resulting optimal values. Thus, we would have values of up to 90% (E4) with respect to a new building (E5).

State	Energy classification	Heating demand kWh/m <sup>2</sup>	Total Primary Energy Consumption kWh/m <sup>2</sup>	Total CO <sub>2</sub> emissions Kg CO <sub>2</sub> /m <sup>2</sup>
State 0	E	128.3	170.2	37.0
State 1	D	80.3	110.9	23.9
State 2	D	77.8	107.9	23.7
State 3	D	64.5	92.2	20.1
State 4	C	49.5	73.9	16.1
State 5	C	42.3	65.3	14.3

*Table 2. Results of the different hypotheses of the original state (E0), interventions (E1, E2, E3 and E4) and reconstructions or new building (E5).*

## 9. Conclusions.

After analysing the baseline data and having obtained the current energy performance of this building model, we can analyse the consequences of the different energy interventions proposed. The first conclusion is that the energy performance of this model, both due to their urban development characteristics and to their constructive implementation, is not, in principle, bad. However, to achieve the level required by the current regulation, its energy improvement must be carried out. We have verified, in this regard, that only by intervening

on its construction elements and not taking into account the installation systems, it is not possible to reach an improvement limit that is required by the current DB-HE. If we take the maximum improvement level that can be obtained without intervening on the installations as reference (E5), we see that, with partial solutions (E1, E2 and E3) that have no impact on the architecture of the building, reasonably satisfactory results can be reached. If we take part on the use or habitability of the users we can get better results (E4).

State	Improvement respect to State 0 %		State	Improvement respect to State 5 %
State 0	-		State 0	0
State 1	35		State 1	52
State 2	39		State 2	55
State 3	46		State 3	72
State 4	57		State 4	90
State 5	67		State 5	-

Table 3 and 4. Relative comparative values between solutions with respect to State 0 and State 5.

#### Notes:

\* The reference computer program, Calener-VYP, has been used to make the calculations to qualify the energy efficiency of the buildings of dwellings, and of the small and medium tertiary, in its Version 12/06/13. The new version of the program, the unified Lider-Calener tool was published after making the calculation, updated on 15 March 2014.

\*\* CTE or Código Técnico de la Edificación, is the Spanish Technical Building Code. The DB-HE1 is the Basic Document on Energy Saving, Limitation of energy consumption.

\*\*\* The Climate Zone adopted has been described as included in the application of the Calener VYP program used, version 12/06/13, which was Climate Zone C1. Now, San Sebastian forms part of Climate Zone D1, as included in the latest modifications of the DB-HE, of 2013.

Further information: <http://www.codigotecnico.org/>

#### References

- [1] Directive 2010/31/UE of the European Parliament and Council, of 19 May 2010, related to Energy Efficiency in Buildings (Recast). DOUE L153/13, 18.6.2010. <https://www.boe.es/doue/2010/153/L00013-00035.pdf>
- [2] Declaration of Toledo. Informal meeting of Ministers of Urban Development. Declaration of 22 June 2010. [http://www.fomento.gob.es/NR/rdonlyres/1A96C491-E5B2-4EE0-8C3A-7FB551D031E9/95943/Decla\\_Toledo\\_aproba.pdf](http://www.fomento.gob.es/NR/rdonlyres/1A96C491-E5B2-4EE0-8C3A-7FB551D031E9/95943/Decla_Toledo_aproba.pdf)
- [3] Order FOM/1635/2013, of 10 September, which updates the Basic Document, DB-HE “Energy Saving” of the Technical Building Code, approved by Royal Decree 314/2006, of 17 March. Official State Journal, no. 219, pg 67137 to 67209 (73 pages) of 12 September 2013. <http://www.codigotecnico.org/web/recursos/documentos/>
- [4] Instituto Nacional de Estadística - INE. <http://www.ine.es/>
- [5] Martín Ramos, A. (2011). *El efecto Cerdà. Ensanches mayores y menores*. Universitat Politècnica de Catalunya.
- [6] Martín Ramos, A. (2004). *Los orígenes del ensanche Cortázar de San Sebastián*. Barcelona. Fundación Caja de Arquitectos.
- [7] Aste, N.; Angelotti, A.; Buzzetti, M. (2009). The influence of the external walls thermal inertia on the energy performance of well insulated buildings. *Energy and Buildings*. 41 (2009): 1181-1187: doi0.1016/j.enbuild.2009.06.005
- [8] Royal Decree 2419/1979, of 6 July, which approves the basic building standard, NBE-CT-79, on thermal conditions in buildings. Official State Journal, no. 253, of 22 October 1979, pgs 24524 to 24550. <http://www.boe.es/buscar/doc.php?id=BOE-A-1979-24866>

## **Sustainable Improvement and Management for Deteriorated Urban Area In Developing Countries**

**Afify, Ayman**

Beirut Arab University BAU, Beirut, Lebanon

**Abstract:** *The protection and sustainable renovation of old urban area is one of the key actions for sustainability during the rapidly urbanization process in developing countries. The sustainable management of existing building is one of the key fields for the improvement of old urban residential area. Where sustainable renovation defined as a process for maintaining and renovating buildings with due care for existing architectural, cultural, and social qualities and attention to the impact on the natural environment, on people's health and well-being. In this paper, the significance and the demands of sustainable renovation for old urban residential demands a multidisciplinary approach, incorporating environmental, technical, cultural and social factors, as well as the cooperation of different participants., in addition, the general planning framework of sustainable renovation composed of existing building improvement, environmental quality improvement and weak population improvement was set up.*

*However, different sustainability goals often come into conflict with each other and demand choices and compromises. Renovation projects are often more influenced by economic considerations than by care and concern for existing qualities. The challenge for sustainable renovation policies should therefore be to combine respect for the character of the place with high quality design of sustainable measures. The paper concludes that to maintain sustainability of the renewal and urban conservation approaches, the typical urban tissue and essential qualities of the historic areas and of the life of the communities, residing there should be maintained, while adapting the physical structures and activities to some of today's requirements*

**Key, Sustainable development; urban rehabilitation and revitalization; Environmental quality; deteriorated urban area**

### **1. Urban Heritage in Developing Countries**

#### **1-1 Definition of the Cultural and National Heritage**

If we want to define "Urban Heritage", what comes to the mind of the most urban planners are usually "monuments" i.e. all sorts of the old religious buildings, palaces, castles, historical city walls and gates and other type of institutional buildings (e.g. of education, science, social purposes,). This understanding often excludes historic residential areas and historic city centers which equally represent the urban heritage. In addition, there may even be non-tangible elements of urban heritage, such as customs and beliefs that play a role for the articulation of space use and the built environment. (1).

Refereeing to the General Conference of UNESCO, the seventeenth session, the following shall be considered as "cultural heritage". (2)

- a. **Monuments:** architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and

combinations of features, which are of outstanding universal value from the point of view of history, art or science;

- b. **Groups of buildings:** groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science;
- c. **Sites:** works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view.

#### 1-2 The Current Situation of Old Urban Stock In Developing Countries.

During the last four decades, the attention of most governments in the developing countries has been focused on the problems of new settlements built through the formal and informal processes. Typically, most of these areas grow rapidly and were characterized by overcrowding, lack of infrastructure, poor-quality construction, bad sites, and so forth. At the same time, the desire for “modernization” by Governments and decision-makers in most developing countries often led them to believe in new and modern style. Anything old or in traditional style was considered of little value and was torn down or at best ignored. (Image1) present the old urban stock in the inner city areas in Cairo, which are suffering from lack of infrastructure, poor-quality construction.



*Image 1 the old urban stock in El Moaied Mosque area – Cairo.*

In addition, because of the rapid growth in the size of most cities in developing countries, and the transformation of their city economics, the whole spatial pattern of land uses and activities began to change. Inner cities became valuable for land uses other than housing, and economic pressures led to further elimination of older urban stock. For all of these reasons, most cities in developing countries have been paid till now very little attention to their older urban areas.



As a result, these areas continue generally to decline, with their physical, social and economic functions disrupted and their present potential contribution to the city's overall urban stock under-utilized. On the other hand, most old cities have some Urban Heritage and monuments, which represent the religious, military, political or economic powers of the past as in (Image2).



*Image 2 the current situation of El Moaied Mosque area.*

The condition of such monuments is determined largely by their present function and use. Monuments, which have no future utilization, tend to decay rapidly, while monuments, which are still in use have a better chance of being maintained. There is a good chance that monuments, which have a new function through “adaptive re-use”, are even better maintained. In fact, the strategy of conversion of monuments for adaptive re-use appears to be the most effective approach for a self-financing and sustainable form of conservation. There is, of course, a very large variety among urban heritage monuments throughout the whole world (Africa, the Middle East, Asia, and Latin America), hence, it is difficult to generalize with regard to their conditions and possibilities for conservation and rehabilitation. Generally speaking, there is tremendous shortage of funds and institutions that can deal with the management of conservation projects or maintenance of government owned registered monuments.





## 2. Developing the Conservation & Rehabilitation Concepts.

Until the 1940s few countries in the world appreciated the value of their older cities. In Europe, conservation was limited to a concern for historical building of special importance, usually castles, palaces, churches, museums and other significant public buildings. Attention was focused on the monuments individually, considered in isolation from the urban surroundings. After the Second World War, a mass destruction was happened for the historical cities in Europe, which provided the stimulus for a more serious consideration of older urban areas. The re-building which occurred across Western Europe in the 1950s and 1960s led to a much greater awareness of the unique character of these older areas and the need to treat them sensitively and constructively. (3)

At the same time, in Europe and North America, there was growing criticism of the 'modern school of architecture' and the 'bulldozer' school of planning and urban renewal, which generated great dissatisfaction, as whole areas were indiscriminately destroyed and their social communities thoughtlessly ruined. Professionals housing and planning started to formulate new concepts and approaches, which slowly won acceptance from politicians and bureaucrats. (4)

From these various experiences has emerged the idea of urban rehabilitation. This does not mean the wholesome preservation of everything, which is old. Instead, it means the creative use and reuse of older quarters of the city, taken as a whole. Where possible, old buildings are repaired and modernized, to facilitate their continued use, especially as housing. This often includes upgrading of infrastructure services, but on a modest scale, allowing the preservation of incorporated, but on a small scale. Demolition should normally be reserved for structurally unsound buildings, but may also sometimes be needed in order to provide space for essential social services, infrastructure or open space. (5)

While the Venice Charter was still only concerned with single monuments, the UNESCO Conservation introduced for the first time the concept of cultural heritage, which is the basis for area conservation and rehabilitation concepts. Although the concept of rehabilitation has seen increasing support in most of the industrialized countries, a very different situation exists in the developing countries. The concept is still new and unfamiliar in most places. Intellectually and professionally it remains limited to heritage societies, a small number of foreign-trained local professionals, and eventually a few external advisors. Politically, it has not yet generated significant support. Legal and administrative machinery for historic area conservation, where it exists, is largely prohibitory rather than constructive and is seldom effectively enforced. Older housing area, as in (Image 3) is still seen as "problems" rather than as important components of urban life. According to Article 5 of the General Conference of UNESCO in Paris from 17 October to 21 November 1972, at its seventeenth session:

- a. To ensure that effective and active measures are taken for the protection, conservation and presentation of the cultural and natural heritage situated on its

territory, each State Party to this Convention shall endeavor, in so far as possible, and as appropriate for each country:

- b. To adopt a general policy which aims to give the cultural and natural heritage a function in the life of the community and to integrate the protection of that heritage into comprehensive planning programs;
- c. To set up within its territories, where such services do not exist, one or more services for the protection, conservation and presentation of the cultural and natural heritage with an appropriate staff and possessing the means to discharge their functions;
- d. To develop scientific and technical studies and research and to work out such operating methods as will make the State capable of counteracting the dangers that threaten its cultural or natural heritage;
- e. To take the appropriate legal, scientific, technical, administrative and financial measures necessary for the identification, protection, conservation, presentation and rehabilitation of this heritage;
- f. To foster the establishment or development of national or regional centers for training in the protection, conservation and presentation of the cultural and natural heritage and to encourage scientific research in this field.



*Image 3 the deterioration in the old housing stock in El Moaied Mosque area - Cairo.*

Experience in many countries has shown that it can be less costly to restore and modernize old building than was originally expected. In contrast, the cost of demolition and replacement by new buildings has almost always turned out to be more expensive than expected. Naturally, many mistakes were made in the early years of rehabilitation efforts; some projects were failures, some were far too expensive and some succeeded at the expense of the original



residents. Nonetheless, the trend of the experience is favorable, leading to a steadily growing support in countries throughout Europe and elsewhere. By 1964, International Commission on Monuments and Sites ICOMOS had promoted with the Venice Charter, the establishment of the conservation approach for historical monuments. And in 1972, many developing countries signed up for UNESCO's Conservation Concerning the Protection of the World's Cultural and National Heritage, and by 1977 the listing of world heritage sites had begun. While the Venice Charter was still only concerned with single monuments, the UNESCO Conservation introduced for the first time the concept of cultural heritage, which is the basis for area conservation and rehabilitation concepts. (6)

Although the concept of rehabilitation has seen increasing support in most of the industrialized countries, a very different situation exists in the developing countries. The concept is still new and unfamiliar in most places. Intellectually and professionally it remains limited to heritage societies, a small number of foreign-trained local professionals, and eventually a few external advisors. Politically, it has not yet generated significant support. Legal and administrative machinery for historic area conservation, where it exists, is largely prohibitory rather than constructive and is seldom effectively enforced. According to Article 5 of the General Conference of UNESCO in Paris from 17 October to 21 November 1972, at its seventeenth session:

To ensure that effective and active measures are taken for the protection, conservation and presentation of the cultural and natural heritage situated on its territory, each State Party to this Convention shall endeavor, in so far as possible, and as appropriate for each country:

- g. To adopt a general policy which aims to give the cultural and natural heritage a function in the life of the community and to integrate the protection of that heritage into comprehensive planning programs;
- h. To set up within its territories, where such services do not exist, one or more services for the protection, conservation and presentation of the cultural and natural heritage with an appropriate staff and possessing the means to discharge their functions;
- i. To develop scientific and technical studies and research and to work out such operating methods as will make the State capable of counteracting the dangers that threaten its cultural or natural heritage;
- j. To take the appropriate legal, scientific, technical, administrative and financial measures necessary for the identification, protection, conservation, presentation and rehabilitation of this heritage;
- k. To foster the establishment or development of national or regional centers for training in the protection, conservation and presentation of the cultural and natural heritage and to encourage scientific research in this field.



### **3. Sustainable development and Managing Urban Heritage Conservation Projects.**

Sustainable development can be defined narrowly or broadly. In the more limited sense, creating the conditions for economic growth while maintaining the stock of natural resources at or above their present level is sustainable economic development. Such development can still occur at the expense of deteriorating social and cultural conditions. A broader definition of sustainable development would add to the above: the achievement of improved social objectives and quality of life for all income groups. With this in mind, it is suggested that sustainable urban development may be defined, for any city, as the maximization of: Economic efficiency in the use of development resources. (7)

Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987). In the same time, meeting basic needs (minimum standards of drinking water, solid waste management, drainage, sanitation and shelter) is an important component of sustainable urban development and addresses the growing importance of urban poverty. Sustainable development is often associated with the conservation of nonrenewable physical resources for the use of future generations. However, sustainable development is not limited to the careful use of physical resources and the environmental urban development initiatives must also be economically and socially sustainable. However, seldom is a cross-reference made between urban heritage and sustainability. The recent concern for sustainability and the "brown agenda" of urban environmental development has completely excluded urban heritage from the sustainability discussion. (8)

A critical challenge is the balance between these aspects - social, environmental and economic. How can improved environmental conditions in historical areas be balanced with creating jobs? How can new service industries be attracted to cities and towns while avoiding social division? These issues of linkages and balance between social, economic and environmental development are particularly important in urban areas because people live and work close together.

#### **1-3 Balancing Development and Conservation**

Upgrading and new development in urban areas are the positive outcomes of economic growth. They raise standards of living and set the stage for continued development. However, the accompanying rise in land values and pressure for high density urbanization can lead to the destruction of historic property and disruption of the traditional urban fabric. This loss of urban neighborhoods and historic sites was once thought to be the price of progress.

However, planners now recognize that preserving the past is an essential part of creating livable, sustainable cities. Conservation of a city's historic and cultural environment enhances the city and the quality of life for residents by: preserving evidence of past achievements and cultural traditions; protecting enjoyable areas of architectural and natural beauty; and Creating energy for development by generating positive identity and civic pride. (9)

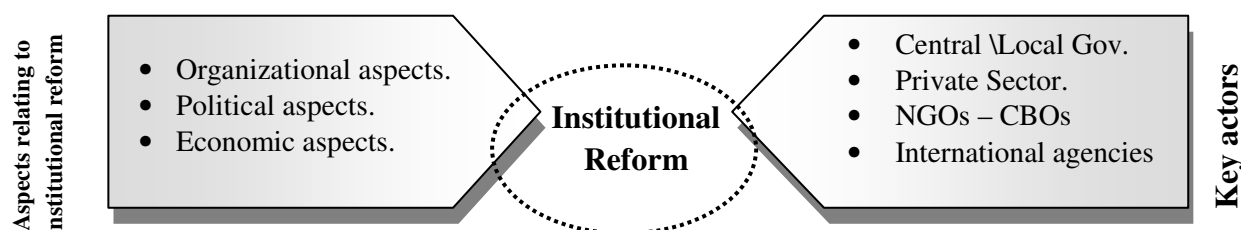
#### 4. Approach to Rehabilitation & Conservation of Urban Heritage.

According to Bromley; the conservation of historical areas in cities of developing counties is often treated as luxury governments can ill afford. In recent years, however, the loss of cultural heritage as a result of the rapid redevelopment of urban fabric is becoming a pressing concern to various developing countries cities. In developing countries, the countervailing pressures of rehabilitation and conservation are being played out in different cultural and economic contexts as cities weigh up on the one hand, the demands of growing population and industries on limited land resources. (10)

Realistically, no one argues for total preservation of everything that is old in the city. Equally, few would quarrel with attempts to improve sanitation and water supply, reduce overcrowding, or otherwise improve the living conditions in older housing areas. Such improvements do provide a more satisfactory environment. But a better environment also implies a satisfying of social and cultural life for those who make use of the environmental resources. Human inhabitants create and constitute the social – cultural and economic systems, which give life to the physical environment. (11)

The focus of conservation and rehabilitation of historical centers, therefor, has to be on whole areas, not just individual buildings, and on social communities, not just the physical environment. These areas are often home for lower-income families, and they have physical, social, economic and cultural values different from the perceptions of the planners. On other words, these rehabilitation policies must emphasize the importance of a comprehensive and integrated approach to planning for older areas. (12)

Therefor, the institutional reform of this conservation and rehabilitation approach raises a variety of crucial issues that that could be summarized in the following chart, (Image 4).



*Image 4, The Relationship and links between the different institutional aspects and all key actors dealing with the rehabilitation & conservation of urban heritage.*





## **5. Conclusions: -**

Rehabilitation and conservation strategies should aim to avoid the idea of static preservation, and not attempt to fossilize the past and convert it into a sort of open-air museum. Therefore, there is an urgent need for rehabilitation approaches which, maintain and sustain the essential qualities of the historical areas in old cities and of the life of the resident communities, but which can also adapt these physical structures and organic approach of revitalization is needed. Adaptation of form and function can proceed, however, within a stable matrix of building and urban patterns. Selectivity is crucial. This implies, for example, a choice of new design concepts and relevant new technologies to enable older buildings and areas to adapt successfully to modern needs but without destroying existing urban form.

To achieve the previous approach, it will be necessary to create a changed political environment in which historical centers are rehabilitated in their true value, and where policies and practice of government are modified accordingly. And it will be necessary to change the attitudes of professionals of (administrators, economists, planners, architects, and developers). Institutions must be developed and economic and administrative instruments for control and promotion must be worked out. In the same time, civic authorities should pay attention to rehabilitation and re-use of old and historical properties which are not under government protection and use. These properties should be listed, and their rehabilitation and re-use should be promoted.

## **Recommendations: -**

The institutional performance of rehabilitation and conservation project depends on the internal organization, including the organizational structure, the management and the availability of skilled staff. The development of the organization and the extent to which it is possible to set and attain the organization's objectives is also interrelated with external institutions such as the government and foreign donors, if any. A necessary condition for successful institutionalization of rehabilitation and conservation programs and projects is the acceptance of the goals, means and scope of the program/project.

The first step to secure this acceptance is to gain support for the policy objectives of development projects. Therefore, the objectives must reflect the interests of the beneficiaries. Sustainable development has tended to be associated with the conservation of non-renewable physical resources for the use of future generation. However, for urban development initiatives to be sustainable they cannot be confined to physical resources and the environment. If the urban economic and social frameworks within which they take are not sustainable, little of lasting value will be achieved. For this reason, the guidelines use the now commonly accepted view of sustainability as concerning connected social, economic and environmental issues.



Participation and partnership are at the center of the strategic approach to effective urban development. Whilst rehabilitation and conservation projects may take place with different actors and stakeholders, participation with different levels of involvement, partnership implies a more equal distribution of responsibility (and benefit) amongst all partners. In order to develop and sustain partnerships on this basis, emphasis must be given to "empowering" and "enabling" all partners, especially those with the least access to power and resources such as low-income households and communities of urban heritage.

## 6. References

1. Steinberg, Florian, Conservation & Rehabilitation of Urban Heritage in Developing Countries- HABITAT INTL., Vol. 20, No. 3, 1996.
2. UNESCO, The General Conference of UNESCO, the seventeenth session – Article 1,5 , Paris, October.1972.
3. O. Graber, Why History; the Meanings and Uses of Tradition, Traditional Dwellings and Settlements Review 4, 2 - 1993.
4. G. B. Dix, 'A Sure and Proper Foundation – Conservation and the Future of Urban Design' Report of the Third International Congress on Architectural Conservation and Town Planning (The Heritage Trust, London, 1987.
5. B.M. Feilden, Architectural and Urban Conservation, Town Planning 56, 2 1985.
6. ICOMOS, The Venice Charter (ICOMOS, Venice, 1994).
7. Reinhard Goethert, "Community Action Planning Report" (GTZ Eco City Programme, 2007).
8. United Nations Conference on Environment and Development, Agenda 21, Pre-conference draft report (United Nations, NewYork, June 1992).
9. Shuhana & Sulaiman. Conservation of Urban Heritage in Malaysia: the Threats, theProspects and the Challenges. UTM. Skudai, Johor (2007)
10. Bromley, R.D.F. and Jones, G.A., Conservation in Quito: policies and progress in historical centre, Third World Planning Review 17-1, 1995.
11. Andrew King, The Politics of Position: Inventing the Past, Constructing the Present, Imagining the Future, Traditional Dwellings and Settlements Review 4,2 – 1993.
12. Brundtland Commission, Report of Our Common Future – World Commission on Environment and Development, Oxford, 1987.



## **The methodology and case study of “Standards for Measuring, Accounting and Reporting of Carbon Emission from Buildings”**

### **Authors:**

Zhang Peng<sup>1</sup>

Wang Yan<sup>1, 2</sup>

<sup>1</sup> China Architecture Design And Research Group, Beijing, China

<sup>2</sup> School of Environmental Science and Engineering, Tianjin University, Tianjing, China

**Abstract:** *The Chinese carbon emission accounting system development started initially and the application on building industry for carbon emission accounting standard is very few. This paper introduces a Chinese standard named “Standards for Measuring, Accounting and Reporting of Carbon Emission from Buildings”, which is authorized by China Association for Engineering Construction Standardization (CECS) and funded by China Ministry of Science and Technology.*

*The paper introduces the methodology proposed in the standard for data collection, accounting and reporting building carbon emissions. A case study in the life cycle carbon emissions of two residential buildings in southwest China, Chengdu, is developed.*

*The result of case study shows that the methodology proposed in the standard for accounting building carbon emissions is workable. Also, It can be used as an important tool for building carbon emissions assessment. Finally this paper provides some scientific technical measures of energy efficiency increase and emissions reduction.*

**Key Words:** *Methodology, Carbon Emission from Buildings, life cycle, energy efficiency*

### **1 Introduction**

Building industry contributes greatly to the social sustainable development. According to the data from UNEP, energy consumption of building industry is 40% of the total social energy consumption and 33% of the global CO<sub>2</sub> emission<sup>[1]</sup>. As the biggest developing country, resources and materials consumed by building construction in China is 40%~50%<sup>[2]</sup> of total domestic resources. Measured by Tsinghua University based on the energy consumption data (2000~2005) from National bureau of statistics of China, the energy consumption from production of building materials, building operation and logistics transportation account for 45% of total domestic energy consumption<sup>[3]</sup>.

In the 12<sup>th</sup> Five-Years Plan, GHG emission control from industrial, building, transportation and agriculture is evidently indicated. The work plan of GHG emission control of 12<sup>th</sup> Five-Years Plan indicates that statistical accounting system of GHG emission should be setup immediately, in order to implement the emission goal of unit GDP carbon emission intensity of 2020 reduction of 40%~45% of 2005.



Based on the background, authorized by China Association for Engineering Construction Standardization (CECS), China Architecture Design and Research Group (CAG) developed a standard “Standards for Measuring, Accounting and Reporting of Carbon Emission from Buildings”, which is also funded by China Ministry of Science and Technology. This standard is based on the Research and Demonstration of Key Technologies Integration in Measuring, Accounting and Reporting of Carbon Emission, and Low Carbon Design for Urban Buildings (2011BAJ07B02), which is one of the 7 topics of Research and Demonstration of Key Technologies Integration in Urban Low Carbon Development (2011BAJ07B00), a research project supported by the state in the 12th Five-years Plan. The paper introduces the main content of the standard, and a case study in the life cycle carbon emissions of two residential buildings (one of them is existing and another is a new building) in southwest China, Chengdu, is developed.

## **2 Background**

The current carbon emission accounting method includes two types as follow:

### **(1) Green building assessment system**

The typical assessment system include LEED of USA, BREEAM of UK, BEPAC of Canada, CASBEE of Japan, Green Star of Australia and Green Mark of Singapore.<sup>[4]</sup> Part of indicators from above-mentioned system can reflect carbon emission results in a range, but they only focus on the direct energy use of building operation. Carbon emission is not considered as a critical index in these assessment systems.

### **(2) Methodology of building carbon emission and carbon emission inventory development**

The methodology is measuring activity data and emission factor related to carbon emission in buildings, accounting and verification of the GHG emission in the boundary and finally the building carbon emission inventory could be collected. The representative methodology and standards include “Common Carbon Metrics” from UNEP SBCI in 2009<sup>[1]</sup>, “Guidelines to account for and report on greenhouse gas emissions and removals for buildings in Hong Kong” in 2010 authorized by Environmental Protection Department and Electrical and Mechanical Services Department of Hong Kong<sup>[5]</sup>, also an international building carbon emission measurement standard is developing by ISO based on “Common Carbon Metrics”.

## **3 Methodology and main content of the standard**

### **3.1 Principle of application**

#### **3.1.1 The measuring, accounting and reporting of carbon emission from buildings shall cover the whole life cycle of buildings**

At each stage of material production, building construction, operation and maintenance, demolition and recycling, there are energy and materials consumption that lead to carbon

emissions and impact on the natural environment. So the measuring, accounting and reporting of carbon emission from buildings shall cover the whole life cycle of buildings.

### **3.1.2 Measuring, accounting and reporting of carbon emission from buildings shall follow the principles of relevance, completeness, consistency, accuracy and transparency**

“Relevance” means that the chosen boundary, materials, data and methods for quantifying carbon emission from buildings can appropriately reflect the situation of relevant carbon emissions from buildings and satisfy relevant requirements; “completeness” means that given the chosen building and measurement boundary, all information on carbon emission should be quantified and reported. Any exclusion needs to be justified; “consistency” means that consistent methodologies should be adopted to quantify and report carbon emission at various life cycle stages. Any changes to calculation scope, boundary or methods should be documented in the same way and recorded clearly; “accuracy” means that any data sources and calculation methodologies in respect of carbon emission from buildings shall be on a reliable and accurate basis; “transparency” means that any references to information on carbon emission from buildings should be reported in an adequate, sufficient and transparent manner.

## **3.2 Main content of the standard**

### **3.2.1 Accounting model**

Accounting model is based on the method of carbon emission factor, shown as formula (1)

$$E = \sum_{i=1}^n (AD_i \times EF_i)$$

(1)

In formula (1),  $E$  is building carbon emission of the GHG (tCO<sub>2</sub>),  $AD_i$  is activity data of the  $i$  type of emission source, energy, resources and materials consumed,  $EF_i$  is carbon emission factor of the  $i$  type emission source.

Building carbon emissions in the whole life cycle are accounting with the formula (2)

$$E_{LC} = E_{SC} + E_{SG} + E_{YX} + E_{CJ} - E_{HS}$$

(2)

In formula (2),  $E_{LC}$  is carbon emission in the whole life stages of building (tCO<sub>2</sub>),  $E_{SC}$  is carbon emission in the materials production stage (tCO<sub>2</sub>),  $E_{SG}$  is carbon emission in the construction stage (tCO<sub>2</sub>),  $E_{YX}$  is carbon emission in the operation and maintenance stage (tCO<sub>2</sub>),  $E_{CJ}$  is carbon emission in the demolition stage (tCO<sub>2</sub>) and  $E_{HS}$  is the deduction amount of carbon emission in the recycle stage (tCO<sub>2</sub>).



### 3.2.2 Data measuring

Activity data (*AD*) can be collected and measured by meters, reviewing and analyzing documents or analysis and estimation according to the following rules:

(1) When the activity data can be automatically monitored, the method of monitoring instrument shall be adopted, to ensure the completeness, continuity and accuracy of the data;

(2) If the activity data cannot be automatically and continuously monitored, data shall be collected and measured by reviewing the technical documents, files, payment bills, financial reports and other documents of the engineering construction projects;

(3) If the activity data cannot be collected and measured through the aforementioned methods, the data shall be measured by analysis and estimation as per relevant formulas.

The common activity data measuring for building carbon emission accounting is shown as table1.

*Table1 common activity data for building carbon emission accounting*

different periods in the life cycle	unit process	activity data		
		material consumption	energy consumption	water consumption
material production	material production	●		
building construction	material transportation		●	
	operation of the construction machines		●	●
	onsite lighting and office activity		●	
operation and maintenance	operation of the equipment system		●	●
	material for maintenance and replacement	●		
	material transportation		●	
	activity for maintenance and replacement		●	●
demolishment	operation of demolishing machines		●	
	transportation of wastes		●	
recycling	recycle of buildings materials	●		

Carbon emission factor (*EF*) shall come from recognized and reliable source. Recently publish data is preferred. Before the establishment of a complete data base on carbon emission factors, the following sources are recommended for carbon emission factors::

- (1) Documents that are officially and consecutively published by authorized organizations;
- (2) Research reports from certified academic research institutions;
- (3) Statistics yearbooks and reports;
- (4) Information on work flow process of factories.

The common carbon emission factors used for accounting building carbon emissions are collected in table2.

*Table2 common carbon emission factors used for accounting building carbon emissions*

materials					
materials	emission factor	source	materials	emission factor	source
ABS	17.984kgCO <sub>2</sub> /kg	[6]	glass	2.79kgCO <sub>2</sub> /kg	[9]
copper	7.924kgCO <sub>2</sub> /kg	[7]	steel	3.55kgCO <sub>2</sub> /kg	[10]
PVC	8.677kgCO <sub>2</sub> /kg	[8]	concrete	0.157 kgCO <sub>2</sub> /kg	[11]
PE	6.398kgCO <sub>2</sub> /kg	[8]	mortar	0.282kgCO <sub>2</sub> /kg	[12]
wood	0.053 kgCO <sub>2</sub> /kg	[9]	brick	0.234kgCO <sub>2</sub> /kg	[12]
energy and water					
Electricity	0.997 kgCO <sub>2</sub> /kWh	[13]	water	0.3kgCO <sub>2</sub> /m <sup>3</sup>	[5]
Nature gas	2 kgCO <sub>2</sub> /m <sup>3</sup>	[14]	gasoline	kgCO <sub>2</sub> /liter	[14]

### 3.2.3 Data reporting

The report on carbon emission from buildings shall include institution that develops the report, the functions and operating status of the buildings, the process of the calculation of the carbon emission of unit processes, carbon emission inventory of the buildings.

*Table3 content of carbon emission reporting*

	data reporting types		details
A	the section on the institution that develops the report	A-1	nature of the institution;
		A-2	purpose of the report and where does the task of measuring, accounting and reporting of carbon emission come from;
		A-3	contact person of the institution and people involved in the process.
B	section on the function and operating status of the buildings	B-1	location and scope of the building;
		B-2	type, function and purpose of the building;
		B-3	the period in the life cycle covered by the report;
		B-4	the unit processes of each period in the life cycle;
		B-5	operation year of the building.
C	section on carbon emission list of the buildings	C-1	carbon emission of different unit processes of the buildings;
		C-2	carbon emissions of different periods in the life cycle of the buildings;

		C-3	the cumulative carbon emission of buildings till present day;
		C-4	total amount of carbon emission throughout the life cycle of buildings;
		C-5	ratio of carbon emission of different periods in the life cycle of buildings.

## 4 Case study of building carbon emission accounting

### 4.1 Basic information

The methodology of building carbon emission accounting proposed in the standard is applied and exemplified in 2 residential buildings located in Chengdu city (in southwest China, the capital of Sichuan Province). In order to guarantee the integrality of carbon emissions activity data, the two residential buildings are built by one company. One is an existing building which was built in 2003, another is a new building which was built in 2012. The basic information of them are summarized in Table4.

*Table4 basic information of 2 residential buildings*

basic information	existing building	new building
building area (m <sup>2</sup> )	3153	7166
building structure	brick concrete structure	concrete frame shear wall structure
above-ground storey number	6	13
underground storey number	1	2
storey height (m)	3.25	3.25
building height (m)	19.5	42.25
building width (m)	12.6	15
building length (m)	38.8	55
service life span (year)	50	50

## 4.2 Results and discussion

### 4.2.1 Materials producing stage

The data of the consumption of 8 major materials are provided by the developer. Concrete, cement and brick are major materials in brick-concrete-structure existing building, accounting for 86.15% of the total materials consumption. Because the new building uses concrete frame shear wall structure, concrete, cement and steel are major materials used, accounting for 88.16% of the total.

*Table5 consumption of materials*

building material	existing building		new building	
	material weight	intensity of material consumption	material weight	intensity of material consumption

	(t)	(kg/m <sup>2</sup> )	(t)	(kg/m <sup>2</sup> )
cement	323.2	102.5	1620.2	226.1
steel	70.3	22.3	586.2	81.8
concrete	385.3	122.2	2682.9	374.4
PVC	29.3	9.3	25.1	3.51
glass	17.5	5.5	16.9	2.4
mortar	44.3	14.1	325.4	45.4
wood	0.95	0.3	4.78	0.67
brick	301.1	95.5	284.2	39.7
total	1171.95	371.69	5545.68	773.89

$E_{SC}$  is calculated from the materials consumption.  $E_{SC}$  of the existing building amounts to 1171.95tCO<sub>2</sub>. Cement, PVC and steel are major three parts of its carbon emission, accounting for 83.9% of the total.  $E_{SC}$  of the new building amounts to 4482.43 tCO<sub>2</sub>. Steel, cement and concrete are major three sources, accounting for 91.3%. The result shows that the carbon emission will be largely increased if the steel, PVC and cement are used. Using more bricks and woods will help reduce the carbon emission.

Table6 comparison of carbon emissions in materials producing stage

building material	existing building			new building		
	material weight (t)	carbon emission (tCO <sub>2</sub> )	intensity of carbon emission (kgCO <sub>2</sub> /m <sup>2</sup> )	material weight (t)	carbon emission (tCO <sub>2</sub> )	intensity of carbon emission (kgCO <sub>2</sub> /m <sup>2</sup> )
cement	323.2	317.4	100.67	1620.2	1591.0	222.02
steel	70.3	249.67	79.18	586.2	2081.0	290.40
concrete	385.3	60.5	19.19	2682.9	421.2	58.78
PVC	29.3	254.2	80.62	25.1	217.8	30.39
glass	17.5	13.3	4.22	16.9	12.8	1.79
mortar	44.3	12.5	3.96	325.4	91.8	12.81
wood	0.95	0.05	0.02	4.78	0.27	0.04
brick	301.1	70.5	22.36	284.2	66.5	9.28
total	1171.95	977.98	310.17	5545.68	4482.43	625.51

#### 4.2.2 Construction stage

There are three sources of carbon emission in this stage. The first is the energy consumption when construction materials are transported from factories to construction sites. The second is energy and water consumption of the machines like tower cranes, elevators and concrete pumps. The last is the energy consumption of onsite lighting and office activities. All of the data above come from the reports of project developers. The water consumption's influence on carbon emission is ignored because the water consumption record of the construction cannot be collected.

Table7 energy consumption of materials transportation

building material	existing building			new building		
	material weight (t)	distance of transportation (km)	energy consumption* (l)	material weight (t)	distance of transportation (km)	energy consumption (l)
cement	323.2	68	1736	1620.2	75	9600
steel	70.3	160	889	586.2	200	9262
concrete	385.3	17	517	2682.9	17	3603
PVC	29.3	1900	4398	25.1	1650	3272
glass	17.5	50	69	16.9	50	67
mortar	44.3	38	133	325.4	17	437
wood	0.95	90	7	4.78	90	34
brick	301.1	38	904	284.2	38	853
total			8653	total		27127

\*: the average energy consumption of transportation is 7.6litre gasoline per 1000kg goods per kilometer (resource: 2013 China statistical yearbook)

Table8 energy consumption of construction machines

construction machine		existing building		new building	
machine type	power (kW)	running time (h)	power consumption (kWh)	running time (h)	power consumption (kWh)
tower crane	50	7520	376000	13210	660500
elevator	20	6832	136640	11420	228400
cutting machine	2.5	624	1560	1100	2750
reinforcing steel crooking machine	3	936	2808	1100	3300
reinforcing steel straightening machine	5.5	936	5148	1100	6050
reinforcing steel cutting machine	5.5	936	5148	1100	6050
electric welding machine	23.5	700	16450	772	18142
electro-slag welding machine	45	1530	68850	3680	165600
flash butt welder	100	1420	142000	3160	316000
concrete pump	75	470	35250	873	65475
concrete vibrator	1.1	948	1042.8	1396	1535.6
		total	790896.8	total	1473802.6

Table9 energy consumption of onsite lighting and office activities

construction machine		existing building		new construction building	
machine type	power (kW)	running time	power consumption	running time	power consumption



		(h)	(kWh)	(h)	(kWh)
air conditioning	1.0	None use	None	1996	1996
lighting	0.04	17207	688	51229	2049
computer	0.3	8932	2680	11384	3415
		total	3368	total	7460

$E_{SG}$  of the existing building in this stage amounts to 811.5 tCO<sub>2</sub>, and the new building's amounts to 1538.8 tCO<sub>2</sub>. As the new building used more materials, the carbon emissions of materials transportation are three times as much as that of the existing building, but the intensity of energy consumptions and carbon emissions of new building are effectively reduced by making a more scientific and reasonable construction plan. Its carbon emissions intensity is 214.74 kgCO<sub>2</sub>/m<sup>2</sup>, which is only 83.4% of the existing building.(Shown as the table10)

*Table10 comparison of carbon emissions in construction stage*

building material	existing building			new building		
	energy consumption	carbon emission (tCO <sub>2</sub> )	intensity of carbon emission (kgCO <sub>2</sub> /m <sup>2</sup> )	energy consumption	carbon emission (tCO <sub>2</sub> )	intensity of carbon emission (kgCO <sub>2</sub> /m <sup>2</sup> )
materials transportation	8653L	20	6.34	27127L	62	8.65
construction machine	790896.8kWh	788.5	250.08	14738.2.6kWh	1469.4	205.05
onsite lighting and office activity	3368kWh	3	0.95	7460 kWh	7.4	1.03
total	/	811.5	257.4	/	1538.8	214.74

#### 4.2.3 Operation and maintenance stage

The sources of carbon emission in the operation and maintenance stage include energy and water consumption of the building in the 50 years operation period, materials used for maintenance, materials transporting, energy and water consumption of maintenance activities. The data of the energy and water consumption of the buildings is collected from the measuring meters. The existing building uses the average data of 2004 to 2013, and the new construction building uses the data of 2013.

*Table11 energy and water consumption of building operation*

building	electricity (kWh/a)	nature gas (m <sup>3</sup> /a)	water (m <sup>3</sup> /a)	record period
existing building	74671	8346	4042	2004-2013
new construction building	227957	22645	7754	2013

Among the 8 materials listed above, PVC, glass and wood will be replaced for interior fitting out and exterior surface maintenance. Given the maintenance takes place every 15 years, the existing building will use 143.25t materials for maintenance in the 50-years operation period and another 2113L gasoline for transportation. The new building will use 140.34t materials and 2070L gasoline.

*Table12 consumption of materials and transportation energy for maintenance activity*

building	times of material replace	material weight (t)			Total (t)	energy consumption of materials transportation (l)
		PVC	glass	wood		
existing building	3	87.9	52.5	2.85	143.25	2113
new building	3	75.3	50.7	14.34	140.34	2070

The property management companies are usually responsible for the building's daily maintenance in China. To simplify the calculation, the property management company's energy and water consumption are taken as the energy consumption for maintenance activities in the cases, that is 5%, told by the managers of the two buildings, of the building's total energy and water consumption within a year.

*Table13 energy and water consumption of maintenance activity*

building	electricity (kWh/a)	gas (m <sup>3</sup> /a)	water (m <sup>3</sup> /a)
existing building	3733.55	417.3	202.1
new building	11397.85	1132.25	387.7

In the operation and maintenance stage,  $E_{YX}$  of existing building is 5656 tCO<sub>2</sub> in total with carbon emission intensity of 35.88 kgCO<sub>2</sub>/m<sup>2</sup>·a, and the new building is 21096 tCO<sub>2</sub> with carbon emission intensity of 58.87 kgCO<sub>2</sub>/m<sup>2</sup>·a. The major reason for the fact that the new building's carbon emission intensity is higher than the existing building's is every family in the new building installs household central air conditioning system while only a few families in the existing building install split air conditioner. As a result, the new building costs much more electricity.

*Table14 comparison of carbon emissions in operation and maintenance stage*

		existing building		new building	
		activity data	carbon emission in 50years(tCO <sub>2</sub> )	activity data	carbon emission in 50years(tCO <sub>2</sub> )
building operation	electricity(kWh/a)	74671	3722.35	227957	11363.66
	nature gas(m <sup>3</sup> /a)	8346	834.60	22645	2264.50
	water (m <sup>3</sup> /a)	4042	60.63	7754	116.31
material replace	PVC (t)	87.9	762.71	75.3	653.38
	galss (t)	52.5	39.90	50.7	38.53
	wood (t)	2.85	0.16	14.34	0.80

material transportation	gasoline (L)	2113	4.81	2070	4.71
maintenance activity	electricity(kWh/a)	3734	186.14	11398	568.19
	nature gas(m <sup>3</sup> /a)	417	41.70	1132	113.20
	water (m <sup>3</sup> /a)	202	3.03	388	5.82
total		/	5656.02	/	21095.76
intensity of carbon emission ( kgCO <sub>2</sub> /m <sup>2</sup> ·a)		/	35.88	/	58.87

#### 4.2.4 Demolishment stage

The sources of carbon emission in the demolition stage includes energy consumption of demolishing machine's and energy consumption of transporting waste from the demolishing site to landfill. The disposal of the waste is not considered in this paper. According to the life cycle assessment result of energy consumption for typical Chinese buildings<sup>[15]</sup>, the average intensity of energy consumption in the demolition stage is 107.7 kWh/m<sup>2</sup>. Demolishing the existing building costs 339578 kWh and the new construction building costs 771778 kWh.

According to the energy consumption,  $E_{CJ}$  of existing building is 338.56 tCO<sub>2</sub> and the new construction building's is 769.46 tCO<sub>2</sub>. The result reflects the scale difference of the two projects.

#### 4.2.5 Recycle stage

Some materials can be recycled after demolition, so the embodied carbon of these materials should be deducted from the total amount of carbon emission in a building's life cycle. According to the average recycle rate of the major materials, recyclable materials of the two buildings can be estimated (shown as the table15). The total amount of the recyclable materials of the existing building is 564.69t and the recovery rate is 48.2%. The total amount of the recyclable materials of the new construction building is 2681.46t and the recovery rate is 48.4%. In the recycle stage,  $E_{HS}$  of the existing building is 453.34 tCO<sub>2</sub> and the new construction building is 2652.56 tCO<sub>2</sub>. From the life cycle perspective, recycling materials has a remarkable effect on saving energy and reducing carbon emission.

Table15 comparison of carbon emissions deduction in recycle stage

building material	recycle rate <sup>[16]</sup>	existing building		new building	
		recycle material weight (t)	carbon emission deduction (tCO <sub>2</sub> )	recycle material weight(t)	carbon emission deduction (tCO <sub>2</sub> )
cement	20%	64.64	63.48	324.04	318.21
steel	95%	66.785	237.09	556.89	1976.96
concrete	60%	231.18	36.30	1609.74	252.73
PVC	25%	7.325	63.56	6.275	54.45
glass	80%	14	10.64	13.52	10.28

mortar	0%	0	0.00	0	0.00
wood	10%	0.095	0.01	0.478	0.03
brick	60%	180.66	42.27	170.52	39.90
total		564.69	453.34	2681.46	2652.56

#### 4.2.6 Life cycle carbon emission inventory

The existing building will emit 7353.73 tCO<sub>2</sub> in its whole life cycle stages. And its carbon emission intensity is 46.65 kgCO<sub>2</sub>/m<sup>2</sup>·a in the 50-years operation period. The new building will emit 19336.64 tCO<sub>2</sub> in its whole life cycle stages with carbon emission intensity 53.97 kgCO<sub>2</sub>/m<sup>2</sup>·a in the 50-years operating period. In the building's life cycle, most of carbon is emitted in the maintenance stage. The existing building's carbon emission in the maintenance stage accounts for 72.4% percent of a life cycle amount and the new building's accounts for 68.8%.

Table16 life cycle carbon emission inventory

Different periods in the life cycle	unit process	carbon emission (tCO <sub>2</sub> )	
		existing building	new construction building
material production stage	material production	977.98	4482.43
building construction stage	material transportation	20	62
	operation of the construction machines	811.5	1538.8
	onsite lighting and office activity	3	7.4
operation and maintenance stage	building operation	4617.58	13744.47
	material for maintenance and replacement	802.77	692.71
	material transportation	4.81	4.71
	activity for maintenance and replacement	230.87	687.21
demolishment stage	operation of demolishing machines	338.56	769.46
	transportation of wastes		
recycle stage	recycle of buildings materials	-453.34	-2652.55
total		7353.73	19336.64
Intensity of carbon emission in whole life cycle stages (kgCO <sub>2</sub> /m <sup>2</sup> ·a)		46.65	53.97

#### 4.3 Measures for CO<sub>2</sub> emissions reduction

According to the result of the case study, the measures of reducing carbon emissions are proposed as follows.



(1) In the materials producing stage. Lighten the building's structure as much as possible. The lighter the structure is, the less the materials will be used. As a result, the carbon emission will be less. Use more high-recycle-rate materials like steels and bricks. Use more materials like woods and stones which could be processed easier. The materials that need more complicate processing techniques will cause more carbon emission.

(2) In the operation and maintenance stage. Improve the building envelope thermal performance and reduce the building's load of heating and cooling. Use more clean energy like solar and use less fossil energy. Use high-efficient air-conditioner, heating system and lighting system. Help people raise energy-saving awareness and develop habit of energy-saving and carbon-cutting.

(3) In the construction and demolishment stage. An industrial and standard constructing method should be employed to cut energy and resource consumption. Enhance the usage rate of the waste and old materials.

## 5 Conclusions

This paper introduces the methodology proposed in the "Standards for Measuring, Accounting and Reporting of Carbon Emission from Buildings" for data collection, accounting and reporting building carbon emissions, then an case study of two residential buildings is taken. The life cycle carbon emissions of the two residential buildings are estimated on the basis of consumed energy and resources at each stage. The life cycle carbon emission of the existing building is 7353.73 tCO<sub>2</sub>, and the intensity of life cycle carbon emission is 46.65 kgCO<sub>2</sub>/m<sup>2</sup>•a (service life span is 50 year), the new construction building is 19336.64 tCO<sub>2</sub> and 53.97 kgCO<sub>2</sub>/m<sup>2</sup>•a.

The result of case study shows that the methodology proposed in the standard is workable, Also it is an effective tool for building designers and policy-makers to take much of the further balances between the life cycle carbon emission and value creation of a building.

## 6 References

- [1] UNEP. SBCI. (2010). Common carbon metric-Protocol for measuring energy use and report greenhouse gas emissions from building operations[R].
- [2] Wu Xin. (2005). The research of construction project environmental impact evaluation method[D] (in Chinese). Tsinghua University.
- [3] Li Zhaojian, JianYi. (2006) The analysis of building energy consumption of China. Architectural Journal. (in Chinese), 2006(7): 30-33.
- [4] S. Thomas Ng, Yuan Chen, James M.W. Wong (2013). Variability of building environmental assessment tools on evaluating carbon emissions[J]. Environmental impact assessment review, 32(1): 131-141.





- [5] EPD. EMSD. (2010) Guidelines to account for and report on greenhouse gas emissions and removals for buildings in Hong Kong[R].
- [6] JiangJinlong, XuJincheng. (2006) Life cycle assessment of ABS plastic. Journal of ZhengZhou University. (in Chinese) 38(2):59-63.
- [7] GuLijin. (2009) Life cycle environmental impact assessment of Chinese construction industry[D]. (in Chinese). Tsinghua University.
- [8] ChenHong, HeWeichang, ShiFeng. (2004) Life cycle assessment of some typical polymers materials. Journal of Environmental Sciences. (in Chinese) 24(3): 545-549.
- [9] ChenYousheng. (2002) Life cycle assessment on the reduction of carbon dioxide emission of buildings[D] (in Chinese). National Cheng Kung University.
- [10] GongZhiqi. (2004) Quantitative assessment of the embodied environmental profile of building materials[D]. (in Chinese). Tsinghua University.
- [11] ZhaoPing, TongJifeng, MaJuanrong.(2004) The research on the system of the building material environment load index and evaluate[J]. China Building Materials Science & Technology. (in Chinese) 2004(6): 4-10.
- [12] LuoZhixing, YanLiu, LiuJiaping. (2011) Research on building materials carbon emission calculation method and emission reduction strategies[J]. Building Science. (in Chinese) 2011(4): 4-11.
- [13]<http://www.ccchina.gov.cn/archiver/cdmcn/UpFile/Files/Default/20130917081426863466.pdf>. 2013 Baseline Emission Factors for Regional Power Grids in China
- [14] IPCC. (2001) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories[R].
- [15] CaiXiangrong, WangMinquan, FuBoquan. (2010) Analysis of residential building carbon emissions and measures of energy saving and emission reduction[J] Journal of Disaster Prevention and Mitigation Engineering. (in Chinese) 30(9): 428-431.
- [16] LuKaian. (1999) Current situation of construction waste and comprehensive utilization in China[J]. Construction Technology. (in Chinese) 1999(5): 46-47.

### **Acknowledgement**

The research in this paper is funded by China National “Twelfth Five-Years” S&T plan with project number of 2011BAJ07B02. Thanks to the special contribution from Prof. He Jianqing and Prof. Jin Ruidong. Thanks to Chengdu Jiaoda Real Estate Co.,Ltd. for providing primary data of the residential buildings in this paper.

## Effects of façade on the energy performance of Education Building in Saudi Arabia

Ashraf, N<sup>1</sup>; Al-Maziad, F<sup>2</sup>

<sup>1</sup>University of Dammam, Dammam, Saudi Arabia

<sup>2</sup>University of Dammam, Dammam, Saudi Arabia

**Abstract:** *This paper aims to examine the energy performance of a multi-story education building in Saudi Arabia, by changing the settings of façade, keeping other parameters (orientation, HVAC systems illumination load, etc.) at their standard values. Simulations were carried out for different types of facades by using DesignBuilder 3.0 software for calculating the energy consumption. From the simulation result the best façade were selected and their economic viability was studied. It was found a significant effect on energy consumption and cooling load on the change of façade, as a result of which utility operational costs are reduced significantly. The result of the paper enables to select the optimum alternative of façade; to assist decision makers to reduce the energy consumption of buildings.*

**Keywords:** *Energy performance, Building facades, operating costs, Energy consumption, Simulation, optimum alternatives*

### 1. Introduction

Façades not only shape the appearance of building, they also determined the indoor climate, energy consumption and operating costs of a building. They directly influence the heating and cooling loads, and also indirectly influence on lighting loads when day lighting is considered. In addition to being a major determinant of annual energy use, they can have significant impacts on the cooling system and electrical demand. However, they are prominent architectural and design elements and they responsible of occupant's performance, satisfaction and comfort.

Air conditioning systems in buildings in Saudi Arabia are responsible for about 70% of their energy consumption [1]. Whereas the electric consumption for air-conditioning in United Kingdom and United States is 22% and 21% respectively as the analysis provided by Saudi Electric Company. Also, according to the same analysis the average electricity consumption of an apartment in Dammam is 20,000 kWh/yr, while the average consumption of areas of similar climates in the United States is 8000-10,000 kWh/yr. From this we conclude that buildings are large consumers of energy in Saudi Arabia and therefore prime candidates for energy conservation activities. Since they are replaced very slowly and most of the existing buildings do not meet energy efficient standards, retrofitting would be essential to minimize energy usage. At least cost energy strategy conservation should be supported in the energy future. For every unit of energy saved by a given measure of technology, resources will be saved, and the annual maintenance costs of producing the unit of energy will be eliminated [1-3]. Therefore,

considerable attention is currently been paid on reducing the energy demand for cooling purposes in buildings. Ways to monitor energy consumption of buildings and the prospects of energy saving in residential space cooling have been widely discussed [4–8]. Methods for predicting the annual building cooling energy demand have also been presented in a variety of studies [9, 10]. The demand for energy efficient buildings has made the application of building simulation a must, rather than a need.

Because of the increasing amount of new residential and commercial construction using building facade technologies, it is very important to examine the energy consumption for the building by selecting the effective façade system considering the availability of material in Saudi Arabia. This study aims to examine design factors that could contribute to greater reductions of energy consumption and CO<sub>2</sub> emissions. In comparing several facades with the different U-value, it can be observed that some facade configurations are more thermally effective than others (Table 895\_2).

## 2. Methodology

The test building analyzed in this paper is constructed in a moderately exposed parking area within the compound of University of Dammam, Saudi Arabia and are constructed in such a way that they shield another building from the outdoor winds.

DesignBuilder 3.0 was used to fully integrate the various aforementioned factors (see considerations on the program [11]), to determine hourly building energy loads and specific loads for end users, such as external lights and others. This made it possible to simulate many architectural designs with the aim of obtaining better solutions for the project within the analyzed context. DesignBuilder 3.0 is a computer simulation program used to explore the annual energy consumption pattern of a typical building, simulating its dynamic thermal performance.

At first, several technical visits, followed by surveys were carried out to collect information about the existing building. Through the use of simulation software, a building model was created; based on this model, architectonical modifications were simulated. This building energy-use simulation software uses its own climate data file. Building description for the simulation of program is mentioned in Table 895\_1.

The methodology used to study the building consisted in checking the existing façade configuration and comparing it with other alternatives based on locally available economical façade materials.

Six scenarios were developed by façade alteration in the existing building which effect in reducing cooling loads and hence energy. The results of these alterations were shown in Table 895\_3 that provided input for a critical analysis of these parameters.

*Table 895\_1: Building description for the simulation program*

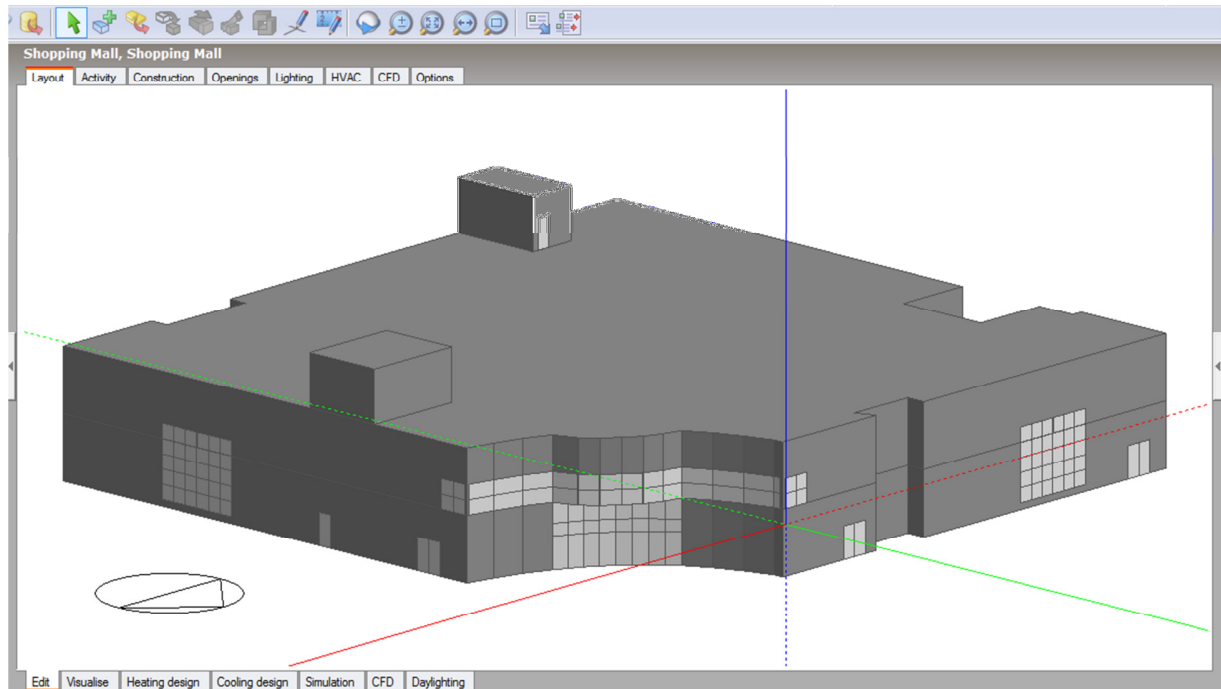
Parameters	Values
No. of floor	3
Total area	4394 m <sup>2</sup>
Floor height	3.7 m
Orientation	North to South
Infiltration rate	5.0 m <sup>3</sup> /h/ m <sup>2</sup>
Ventilation rat	7.5 L/s/person
Thermal zones	Multi-zones
Equipment	20 W/m <sup>2</sup>
Lighting	18 W/m <sup>2</sup>
HVAC	Central System
Occupancy	4.5 m <sup>2</sup> /person
Set point	(22–24 °C) Summer, (20–22 °C) Winter

### 3. Data description

The analysis focus on an institutional building, located in a North Zone of the city of Dammam, Kingdom of Saudi Arabia at latitude 26°23'N and longitude 50°11'E, and temperatures varying from 15.3 °C to 45 °C on average. The building is in an urban area, with medium density occupation. The orientation of its frontal facade is 58° east of North. Construction of the building ended in 2012. The model of the building is shown in Figs. 895\_1.

### 4. Simulation data

A total of six façade configurations have been analyzed. All the façade cases have been formed on the basis of economically feasible materials considering the thermal conductivity into account which affects the heat transfer rate. Wall conductance and resistance values have been computed for all the six cases as shown in Table 895\_2. The values obtained are then used for the simulation of program.



*Fig. 895\_1: Plan and elevations and of the case study building*

## 5. Results and discussions

The properties of the material are inserted into the programme such as specific heat, conductivity, density, thermal absorptance values etc. into the DesignBuilder 3.0 software and the cooling loads and total energy consumption for all six cases of facades have been obtained. The results are shown in Fig. 895\_2.

It is clear from the results that Façade-II configuration has minimum values of annual energy consumption and cooling load.

The air-conditioning system is responsible for a significant share of total energy consumption of the building, approximately 69% (concluded from Fig. 895\_2 and 895\_3). Fig. 2 and 3 shows the office building total annual electric energy and cooling load consumption. For the purpose of discussion the electric energy and cooling load variation is due to the reason of different U values.

From the Table 895\_2, it is clear that the Façade-I has highest value of thermal wall conductance (U) and hence solar energy transfer rate is maximum or in other words the thermal resistance is lowest among the discussed cases. While Façade-II has the lowest value of U which results in highest thermal resistance and hence the lower energy consumption and cooling load.



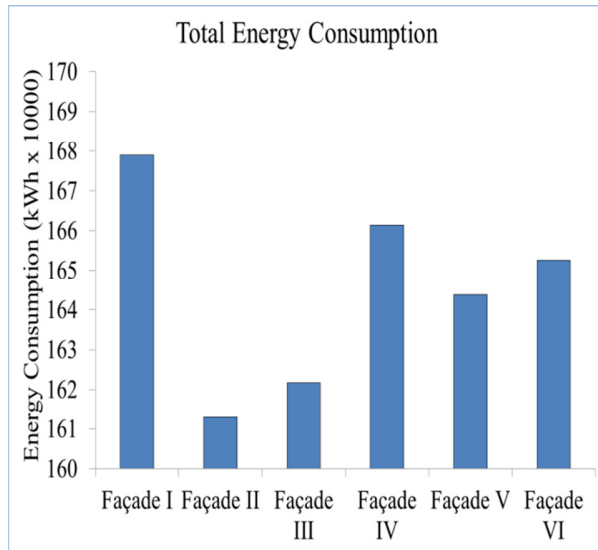


Fig. 895\_2: Annual total energy consumption

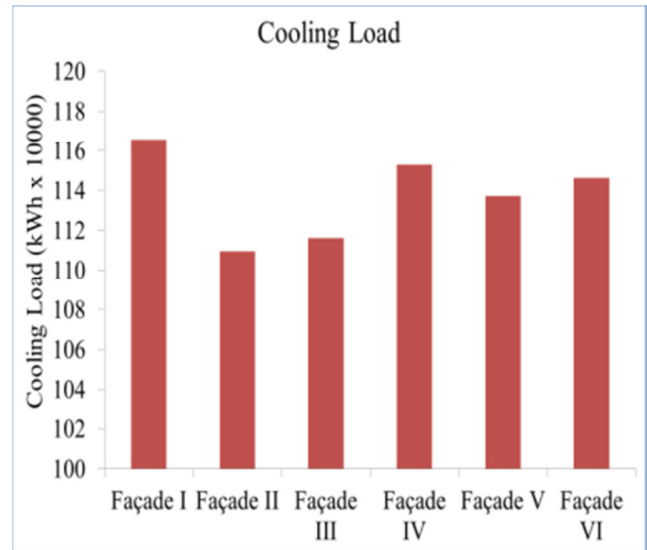


Fig. 895\_3: Annual cooling load

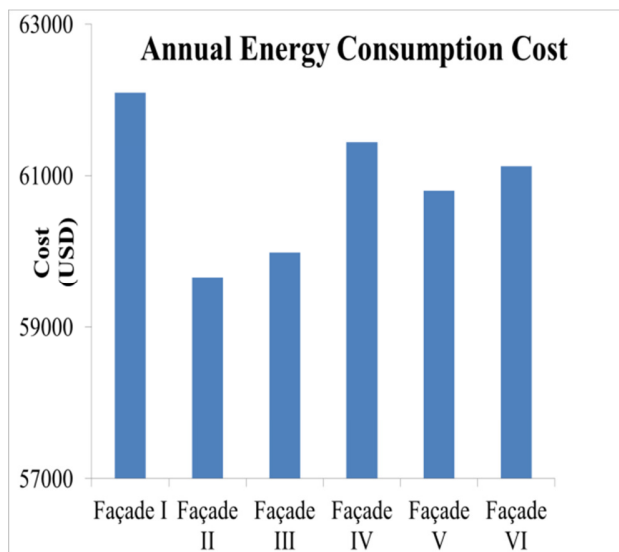


Fig. 895\_4: Annual energy consumption cost

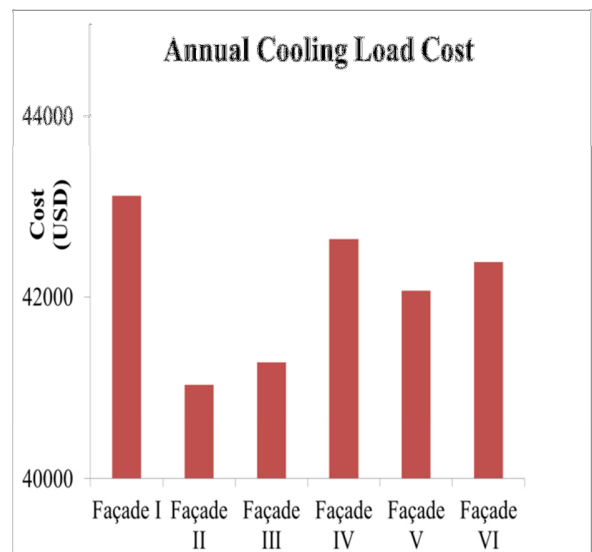


Fig. 895\_5: Annual cooling load cost

Now, it is clear from the results that the façade configuration-II consumes the minimum energy and has minimum cost impact while the existing one consumes the maximum energy and has maximum energy costs. Annual energy consumption per square meter of the area for all the cases has also been calculated and the results are shown in Fig. 895\_6.

Table 895\_2: Annual cooling load: Structures and thermal characteristics of facades used mostly in Saudi Arabia building

Façade Type	Composition	Thickness of wall components (m)	Thermal conductivity of wall components (W/mK)	Wall Conductance U (W/m <sup>2</sup> K)	Wall Resistance (m <sup>2</sup> K/W)
Façade-I	Plaster	0.02	1.5	2.33	0.43
	Concrete Block	0.25	0.62		
	Plaster	0.03	1.5		
Façade-II	Plaster	0.02	1.5	1.47	0.68
	Concrete Block	0.1	0.51		
	Polystyrene	0.05	0.04		
	Concrete Block	0.1	0.51		
	Plaster	0.03	1.5		
Façade-III	Limestone	0.02	1.8	1.64	0.61
	Concrete	0.1	0.51		
	Polystyrene	0.05	0.04		
	Concrete	0.1	0.51		
	Plaster	0.03	1.5		
Façade-IV	Limestone	0.02	1.1	2.13	0.47
	Precast concrete	0.15	1.13		
	Air gap	0.05	0.28		
	Precast concrete	0.1	0.75		
	Plaster	0.03	1.5		
Façade-V	Aluminum	0.01	160	1.82	0.55
	Air gap	0.015	0.28		
	Concrete block	0.25	0.62		
	Plaster	0.025	1.5		
Façade-VI	Terracotta tile	0.02	1	1.92	0.52
	Air gap	0.02	0.28		
	Concrete block	0.25	0.62		
	Plaster	0.03	1.5		

It is depicted from Fig. 895\_2 and 895\_3 that by opting Façade-II instead of base case the annual electric energy consumption and cooling load are reduced by 3.92% and 4.80% respectively. Fig. 895\_4 and 895\_5 shows the cost of annual energy consumption and cooling load for different façade configuration.

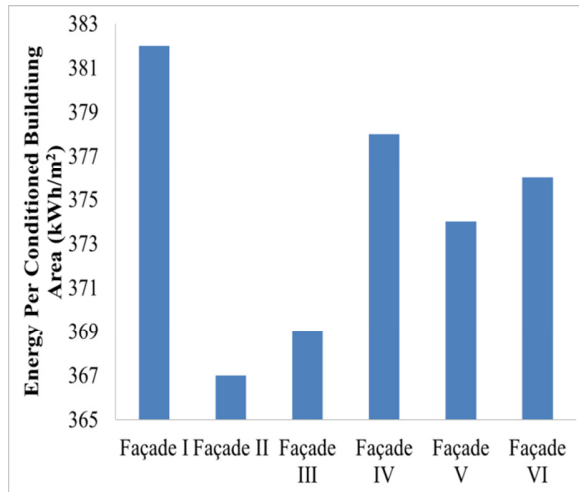


Fig. 895\_6: Energy per conditioned building area

The difference between the annual cost of energy consumption is also significant between the base case (Façade-I) and the best case Façade-II and comes out to be USD 2,439 and USD 2,072 for annual energy and cooling load usage.

## 6. Conclusion

It was confirmed that solar radiation is main source of heat gain in the building. The result shows the importance of façade in preventing solar radiation reaching into the building. Therefore different configuration of facades was developed among the existing economically provided material to minimize the effect. Among them we can cite the use of thermal efficient material with low U factor. The study shows that there is the significant 3.92% and 4.80% of drop in energy consumption by opting the façade-II instead of Façade-I.

Energy conservation and sustainable design in building would make the façade II being the most attractive one among the existing building envelop in Saudi Arabia and should be implemented as it will provide higher rates of comfort accompanied by lower air conditioning energy cost.

## References

- [1] Electrical Affairs Agency (EAA). 2011 *Electricity growth and development in the Kingdom of Saudi Arabia*. Ministry of Industry and Electricity, Riyadh, Saudi Arabia.
- [2] Grondzik, W. (1989) *Architectural applications of thermal insulation*. Al-Mohandis, **2**, pp 2-11.
- [3] Al-Ahmadi, A. (1995) *Thermal performance of insulated layers in buildings subjected to time-dependent and non-linear conditions*. Ms. Thesis, Mech. Eng. Dept., King Saud University.

- [4] Westergren, K. E., Högberg, H., Norlen, U. (1999) *Monitoring energy consumption in single-family houses*. Energy and Buildings, vol. 29, pp. 247–257.
- [5] Mihalakokou, G., Santamouris, M., & Tsangrassoulis, A. (2002) *Energy consumption in residential buildings*. Energy and Buildings 34, pp. 727–736.
- [6] Jaber, J. (2002) *Prospects of energy savings in residential space heating*, Energy and Buildings. 34 pp.311–319.
- [97] Nagai T. (2002) *Optimization method for minimizing annual energy, peak energy demand, and annual energy cost through use of building thermal storage*. ASHRAE Transactions 108 (1) 43–53.
- [8] Binamu A. (2002) *Integrating Building Design Properties ‘Air Tightness’ and Ventilation Heat Recovery for Minimum Heating Energy in Hot Climates*. Ph.D. Thesis, Tampere University of Technology Publications, pp. 377.
- [9] Olofsson, T., Andersson, S., & Östin, R. (1998) *A method for predicting the annual building heating demand based on limited performance data*. Energy and Buildings 28 pp.101–108.
- [10] Olofsson, T., Andersson, S., & Östin, R. (1998) *Energy load predictions for buildings based on a total demand perspective*. Energy and Buildings 28 109–116.
- [11] *DesignBuilder EnergyPlus Simulation Documentation* (2011)
- [12] Haberl, J. S., Bronson, D. J., & O’Neal, D.L. (1995) *Impact of using measured weather data vs TMY weather data in DOE-2 simulation*. ASHRAE Transactions 101 (2) pp. 558–576.
- [13] Ahmad, E. H. (2002) *Cost analysis and thickness optimization of Thermal insulation materials used in Residential buildings in Saudi Arabia*. The 6th Saudi Engineering Conference, KFUPM, Dhahran, December pp. 21-32.
- [14] Carvalho, M. M. Q., Rovere, E. L. E., & Goncalves A.C.M. (2010) *Analysis of variables that influence electric energy consumption in commercial buildings in Brazil*. Renewable and Sustainable Energy Reviews, 14, pp. 3199–3205.

---

## DESIGN AND OPERATION OF A LEED PLATINUM RATED BOTTLING PLANT IN CHINA – SWIRE COCA-COLA LUOHE

**Abstract:** *In 2010, the first Coca-Cola bottling plant in China designed to LEED Platinum standard was in operation at Luohe, Henan province. It employs over 49 sustainability elements reducing 1,200-1,500 metric tonnes/year of GHG emissions and 21,600,000 litres/year of water comparing with conventional design. The key sustainability measures employed include a ground source heat pump system for production; thermal wall insulation; efficient lighting; bloc filling line allowing ambient filling; renewable energy through solar panel and wastewater biogas. Wastewater discharged from the water treatment system is recovered and reused, saving 25 million litres/year of raw water. As part of the site selection process, a source vulnerability assessment was conducted to avoid adverse water impact from future plant operation. Subsequently a source water protection plan was draw-up to ensure sustainable water supply to the plant and the community. This paper will elaborate the challenges encountered during the design stage and evaluate the performance of the plant against the design criteria during operational.*

**Keywords:** *Beverages; Bottling; Design; Leed; Operation; Sustainable.*

### 1. Introduction

Swire Beverages is the principal holding company of Swire Pacific's Beverage Division and has the right to produce, market and distribute The Coca-Cola Company's products in Hong Kong, seven provinces in Mainland China, Taiwan and territories across 11 states in Western USA. Swire's partnership with Coca-Cola began in 1965 and has grown to include 16 bottling facilities with over two million square feet of production premises. Swire Beverages covers a total population of 440 million through 18,000 employees, serving over 800,000 customers who sell beverages to consumers. By producing beverages locally, the business aims to bring economic benefits to the local community in the form of investments, job opportunities and taxes, while amplifying this influence through the partnerships with the customers and suppliers for mutual business growth and supporting local development.

### 2. Swire Coca-Cola Luohe

Swire Beverages celebrated the opening of its most environmental efficient plant to date at Luohe, Henan province in October 2010. The plant is certified to Platinum rating of the Leadership in Energy and Environmental Design (LEED), an internationally recognized green building certification system. The plant has a floor area of 166,000 m<sup>2</sup> with an annual capacity of more than 100 million unit cases serving not only the demand of Henan's 100 million populations but also part of Shaanxi, north of Jiangsu and Anhui provinces.





*Figure 1: Key Design Features of Swire Coca-Cola Luohe*

### 3. Key Design Features

The Luohe plant employs over 49 sustainability elements and is estimated to reduce 1,200-1,500 metric tonnes of GHG emissions per year and 21,600,000 litres per year of water comparing with conventional design. Chief among these are ground source heat pump; thermal insulation; lighting efficiency; bloc filling line; methane gas for power and water savings.

#### 3.1. Production Energy Efficiency

##### 3.1.1. Advanced Production Equipment and Process

The plant has installed with a high speed production line which comes with eco-driven conveying system. Integrated into the design of bloc filling line, bottle rinser and air conveyor system between filler and blower can be eliminated. It also enables ambient temperature filling at 20°C that eliminates usage of conventional ammonia compressor for chill-filling and subsequent warming process that brings filled product to room temperature before packaging.

Raw materials come in at room temperature and products come out also at room temperature but significant amount of energy is used for heating and cooling during production. Potentials are identified to recover the waste heat from cooling process and apply it for heating. For example, hot blast generated from PET bottles blowing process is recovered for ambient heating in the packaging workshop at winter. The plant has also adopted an advanced ambient sugar dissolving system which requires heating only to 85°C for pasteurisation with excess heat being recovered.

A combination of these methods reduces the energy consumption of the plant by 1.7M kWh per year comparing with conventional designs.

### ***3.1.2. Methane Gas Recovery and Reuse***

The plant is equipped with a wastewater treatment facility to ensure the discharge can be returned to the nature safely. Methane gas generated from the treatment process is conventionally flared. This is, however, recovered in Luohe plant to power a small-sized boiler for steam production, which is then used during production, lessening the need for non-renewable energy sources.



*Figure 2: Methane Gas Boiler*

### ***3.1.3. Ground Source Heat Pump***

The earth's temperature below five meters is normally a consistent 15°C. During summer months, when the earth's temperature is cooler than the air temperature, cold energy is extracted from the earth; while in winter months, heat energy is extracted by circulating water through over 120 kilometers of high density polyethylene piping; which is compiled in a matrix of 800 interconnected vertical boreholes of 50 meter depth underground. The heat pump system provides space heating and cooling to the facility, hot and cold water to the bottling lines and heating to the on-site wastewater treatment facility to improve treatment efficiency. Carbon savings are estimated to range from 20% (cooling) to 40% (heating).



*Figure 3: Ground Source Heat Pump (installation)*

### **3.2. Building Energy Efficiency**

#### **3.2.1. Prevention of Heat Loss**

Heat loss is reduced to a minimum using a combination of methods. The walls of plant buildings are all made from heat insulation materials which insulate heat outside effectively. The building windows are low-E glass which does not only allows natural lighting but also has a two-way energy efficiency ability that prevents heat entering in summer and heat releasing in winter. Approximately, 75% of the workshop roofs are highly reflective, with solar reflectance index of at least 78. Such roofs can effectively reject the solar heat in summer so as to reduce the power consumption of air conditioners. The heat loss prevention methods help reduce the energy consumption by 0.06M kWh per year.

#### **3.2.2. Lighting**

The plant has a total surface area of 480 m<sup>2</sup> reinforced translucent fibreglass roof panels and 52 tubular skylights, which can supply natural light up to 75% of the total production area. A total of 629 units of induction lights were installed in the production and warehousing areas and 232 units of T5 energy saving tubes in the office area. Street lamps in front of the office building are all powered by wind & solar. These measures help cut the energy consumption by 0.2M kWh per year and save 180 tons of carbon emissions to the atmosphere.





*Figure 3: Energy Efficient Light Fittings*

### **3.3. Water Savings**

The plant has installed with a multi-layered water treatment system to process the incoming water from the main before production use. The discharge from the water treatment, mainly the reject from reverse osmosis process, is recovered, properly treated and completely reused, saving 25 million litres of raw water a year.

Supply water pipe system is made of HDPE which is rigid and highly resistant to corrosion and can lessen the potential for water leakage due to loading impact and corrosion. This helps improve water use efficiency.

### **3.4. Site Selection and Construction**

During site selection, priority is given to potential sites with access to public transportation to reduce the transportation needs for commuting to and from work. A source water vulnerability assessment study has also been conducted to understand the water demand and supply in the area and ensure no negative water stress will be created to the local community during operation. A source water protection plan was drawn up subsequently to ensure sustainability of water supply to the plant and to the community at operation. The plan is reviewed and maintained regularly.

During construction, measures have been taken to minimise the secondary impacts of the project. The measures include balancing cut and fill, recycling of construction materials, proper disposal of wastes and covering bare soil surfaces sprayed. A waste management plan is drawn up with the construction contractor to ensure a minimum 75% recycling rate of construction materials e.g. concrete, steel, brick, wood and glass, etc.



*Figure 4: Temporary Cover at Fill Bank*

Recycled materials or construction materials with recycled content are used as possible. At least 20% of the construction materials are sourced from 800 km of the site to reduce transportation and encourage local business. Timber from certified sources is used in at least 50% of the materials in the offices.

#### **4. Operational Performance Review and Plan**

With over two consecutive years of full scale operation, the sustainability elements incorporated into the design have demonstrated to be effective. The energy and water usage ratios are 0.17 MJ per litre of production and 1.59 litre per litre of production which are 26% and 0.6% respectively better than the company's average in Mainland China. This is the first time the company has applied the LEED standard at its manufacturing facilities and will consider applying the same or equivalent standards on its future development and project.

#### **5. References**

Swire Beverages, *2010 Sustainable Development Report – In Essence*. Available from: [http://www.swirepacific.com/eng/about/sd/sb\\_report2010\\_11.pdf](http://www.swirepacific.com/eng/about/sd/sb_report2010_11.pdf)

Swire Pacific, *2012 Annual report*.

Available from: [http://www.swirepacific.com/eng/about/sd/sb\\_report2010\\_11.pdf](http://www.swirepacific.com/eng/about/sd/sb_report2010_11.pdf)



## **Rebuilding and a conscious and courageous leadership reduced energy consumption more than 80 percent**

### **Authors:**

Westberg, Johanna (JW)<sup>1</sup>; Holmström, Lars (LH)<sup>2</sup>; Redin, Lisa (LR)<sup>3</sup>.

<sup>1</sup> Umeå University, Umeå, Sweden

<sup>2</sup> Akademiska hus Region Norr, Umeå, Sweden

<sup>3</sup> Umeå University, Umeå, Sweden

**Abstract:** *Akademiska Hus AB has the ambition to halve the energy cost from the year 2000 to 2025. Between 2006 and 2010 the Natural Science Building was renovated completely, and a new presence- and pressure controlled air treatment system was installed. The results show that the investments reduced the heat energy consumption with about 80 percent and the building electricity consumption with about 85 percent. Akademiska Hus AB Region North, had in 2010 built the most energy efficient office building in the region, and still the building is one of the most energy efficient buildings in Umeå. The conclusion of the project is that it is possible with quite easy and also viable investments build more energy efficient than the building Code and the building industry in common requires. A strategic work, ambitious objectives and a conscious and courageous leadership seems to be just as important.*

**Keywords:** *Sustainable building, Energy saving, Energy efficient, Sustainable leadership, Umeå University*

### **Introduction**

In Sweden the building and service sector uses about 35 percent of the energy (1). The sector plays a major role in reaching climate and energy efficiency goals, where the challenge is to switch fossil energy to renewable and replace old inefficient technologies with smart energy efficient technologies.

There are several examples showing the benefits of replacing older installations with newer and more efficient solutions (2). Costs and energy can be saved and new installations may even improve an indoor climate. Despite that, energy saving actions can vary a lot in different companies and branches (1, 3, 4, 5).

There are studies showing that specific driving force and critical factors matter over and above energy reducing goals, when implementing eco-innovations in organizations and industries (6). Previous studies also show that conscious and courageous leadership, inclusions, interactions, system approaches, personal commitments and enthusiasts do matter when implementing long term sustainable aspects in decisions and actions (7, 8, 9). In the building sector even fashion and fad may influence the eco efficiency. Denti and Hemlin (10) studied the relationship between leadership and innovation, and one result was that team climate, team heterogeneity and a creative knowledge environment could influence the will of innovations in an organization. Companies in the branch also point out that the final choice often depend on investment costs and pay-off periods (11, 12).



In Sweden there are laws stating that national authorities and agencies, including the universities, should contribute to a sustainable development and to reduce energy consumption (13, 14). At Umeå University, in north Sweden, issues about sustainable development and environment are important among employees and students. There are also several education programs and research groups that partly, or mainly, focus on questions about sustainable development. The university's environmental policy states that students and employees should be given such conditions and qualifications that encourage them to act in a sustainable way. Further, the university's overall vision points out the importance of research and education in many levels, in creating a human and sustainable development (15, 16).

In 2000, when Akademiska Hus AB Region North, the property owner at Campus Umeå, started the process of renovating and re-building the Natural Science Building at Campus Umeå, the company hadn't just the national climate goals and building regulations to take into account. The company had also their internal energy reducing goals and their own ambitions (11).

In this paper we discuss how factors as leadership, personal commitment and business culture may influence eco efficiencies. We also investigate a specific organization's driving forces for energy saving activities beyond legal requirements. The study also summarize chosen technologies and their energy reduction effect. The study concerns the renovating and re-building in the Nature Science Building at Umeå University, mainly performed between 2006 and 2010.

The following questions are discussed:

1. Which technology was installed and how did the installations affect the energy consumption?
2. In what way does the property owner work with energy reduction and did the property owner take any risk in the work process?
3. Has there been any specific factors that contributed to put energy reducing activities beyond the legal requirements?
4. What lessons can be learned?

### **Method and Materials**

The energy consumption in the Natural Science Building has been measured and reported before and after the renovation and re-building actions. Energy consumption in 2003, 2004 and 2005 (before reconstruction) was compared with the consumption in 2011, 2012 and 2013 (after reconstruction). The data include mean year outdoor climate correction heat energy and electric energy (building electricity and operational electricity).

The head of property management and a property manager at Akademiska Hus AB Region North has been interviewed about performed actions, particular driving forces, risks and experiences from the re-building and renovation in the Natural Science Building.

The Natural Science Building at Umeå University (figure 1) was built between 1965 and 1970. The building consists of three sections, A, B and C and contained mainly teaching laboratories before re-construction. The climate shell is built according to the Swedish Building Regulation of 1965 and the windows are of 2+1 type. The heating and cooling systems are district based. The ventilation before reconstruction was of conventional type with constant supply air and extract and the lighting was a fluorescent light with

electromagnetic ballast that could be manually turned on and off. The area was, expressed as GIA 24 624 m<sup>2</sup> and as GFA 26 731 m<sup>2</sup> in 2005.



*Figure 1: The Natural Science Building at Umeå University. The main energy reduction actions were done in section B and half of section A. Photo: Akademiska Hus*

## Results

### Reconstruction and installations

The re-building and renovating of the Natural Science Building was initiated in 2000, when there was a leakage in the roof in section C. The property owner initiated a long term plan for the complete building. This means that the renovation took place in some parts of section C, but also in the entire section B and in half of section A as there were needs of reconstruction and new functions.

The first action was a re-building of the roof, and a new level, level 5, was added to enable a new ventilation system and new service rooms. Level 5 also enabled new offices. The roof was raised over the entire building, and in section C, in the rooms where the leakage took place, the interior was completely replaced. The remaining parts were prepared for offices but left unfurnished as an insulated cold attic. The level 5 was built according to the current building regulation, with a maximal energy use of 140 kWh/m<sup>2</sup>. During the re-building a small atrium was added to the house and the total area of the building increased from 24 624 m<sup>2</sup> GIA in 2005 to 26 190 m<sup>2</sup> GIA in 2009.

The main installation when renovating has been a complete variable air volume system with intelligent units, manufacturer Lindinvent. The system is installed on levels 2 to 5 and holds a demand-controlled ventilation with minimum ventilation while no presence, normal ventilation while presence and forced ventilation when room temperature increases. The system is also supplied by two aggregates with separate energy gauges which permits measurement of energy use for cooling on each one of them. The tubes are insulated up until served rooms and are designed for low pressure fall, and the supply air to every room is presence controlled. Heat reuse from the extract is with a rotating heat exchanger which is dimensioned for high efficiency. In combination with the 14 degree supply air temperature the result is that extra heat is only needed a few days per year. In rooms served by supply air connected baffles for cooling, which has basic and forced flow, there is a function closing the cool flow to the cooling baffles when the air supply is stopped. Room with circulation cooling and non-priority cooling is provided with a function for limitation of the returning temperature of the cooling water.

The supply air temperature is regulated similarly, that is if more than a certain amount of gauges calls for heat by heating with the radiator, the supply air temperature increases and by

that the heat reuse in the ventilation can be maximized even during spring and autumn. Wintertime the majority of the radiators are needed since the walls are poorly insulated due to an old Building regulation<sup>1</sup> and hence the supply air temperature will be constant. Besides that, the heating system wasn't changed. The Natural Science Building, as well as the whole campus is supplied by district heating.

In the offices the lighting is absence-controlled, connected to a server. When light is switched on the ventilation system reacts and adjust the temperature. When the room is left the ventilation gauge acts on absence after 15 minutes and the lightning is switched off. In the corridors the lights are automatically turned on by presence and dimmed after a chosen time when no one is there.

### Heat energy

The heat energy was measured before, 2003 to 2005, and after, 2011 to 2013, the reconstruction. The result is presented as the energy consumption in kWh per square meter ( $\text{m}^2$ ). The result shows that consumed heat energy decreases from  $152 \text{ kWh/m}^2$  in 2003 to  $18 \text{ kWh/m}^2$  in 2013. This means a reduction of 88 percent. In figure 2 the consumption is shown for the different months.

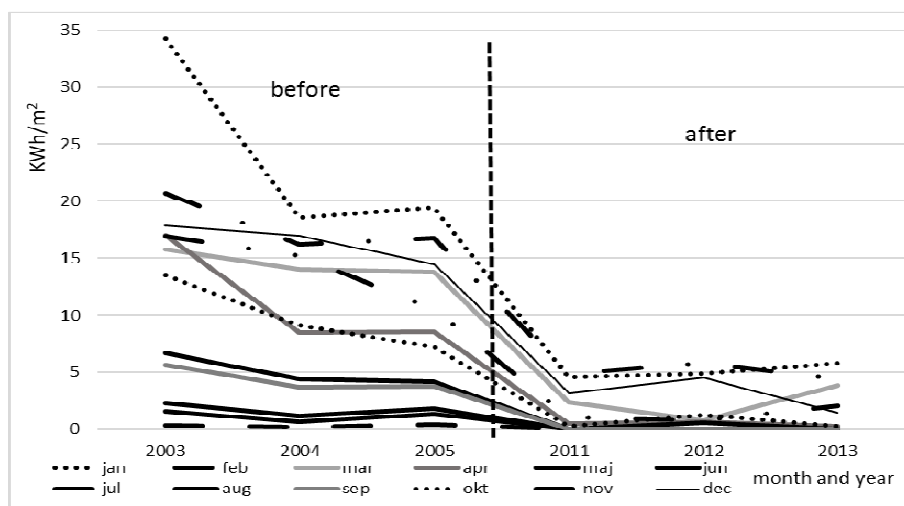


Figure 2: Monthly heat energy in  $\text{kWh/m}^2$  building before and after renovation and re-building.

### Electric energy

The electric energy (including building energy and operational energy) was measured before, 2003-2005, and after, 2011-2013, renovation and re-building. As the GIA, function and purposes of the facility were changed, from teaching laboratories to offices, the values of electric energy should be regarded in light of that. Figure 3 shows that the overall consumed electric energy decreased from  $95 \text{ kWh/m}^2$  in 2003 to  $45 \text{ kWh/m}^2$  in 2013 and that means a reduction of about 50 percent. In some spots, the building electricity (i.e building electricity including light) was measured before and after the re-construction and savings up to 85 percent have been seen.

<sup>1</sup> 100 mm insulation vs. 300 mm that is the Building regulation standard today

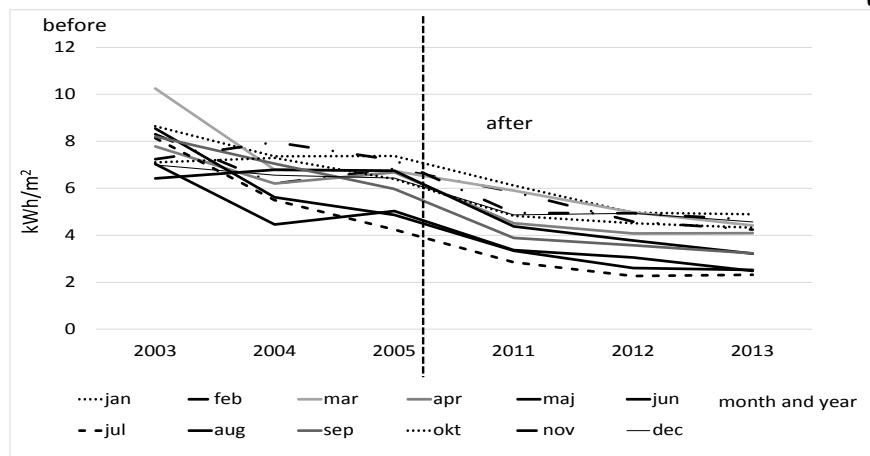


Figure 3: Monthly electric energy (building energy and operational energy) in kWh/m<sup>2</sup> before and after renovation and re-building.

### Working process and possible risks

Akademiska Hus AB Region North has been working strategically with energy reduction and issues concerning sustainable development for about 20 years. In 2005, when main re-construction started, the company had internal goals that meant an energy reduction of 30 percent from the year of 2000 until 2025<sup>2</sup>.

The company also has got an environmental management system (ISO 14001) where the environmental policy shortly states:

*“Akademiska Hus should have an environmental certificate in order to fulfil applicable environmental regulations and other requirements. We should act in order to fulfil the requirements to prevent pollution from the company’s activities. We should also act in a way leading to continuous improvements in the company’s environmental work. We prioritize our work with energy efficiency and development with alternative energy production. For each facility we aim to have the most energy efficient solution.”*

Besides the environmental management system and the internal energy goals, the leadership at Akademiska Hus AB Region North has been important while planning and drawing the re-building and renovation. The leadership has also been important to encouraging the consultants to suggest innovative and long term sustainable solutions. For instance, the VAV-system Lindinvent which gives both ventilation and air condition was chosen. The investment of this system is equal of a conventional system with regular ventilation and cooling baffles but the system demand some additional cost when connecting the system to a server and coupling of light control. Another important factor has been the project leader and his enthusiasm, who has encouraging consultants and construction workers to optimize all installations in order to save as much energy as possible. Also, the project leader’s ambition, that the Natural Science Building should be the least energy consuming building in town has been a driving force.

During interviewing the head of property management and the property manager co-operation in different forms and contexts were expressed as important factors. For instance, co-operation with the tenant, Umeå University, has been important as a re-building and

<sup>2</sup> The goal has been updated and today the goal is 50 percent reduction before 2025 compared to 2000.





renovation mustn't adversely affect the daily activities. The company also co-operates with the Swedish Energy Agency and other commercial property owners in various projects and networks, for instance Akademiska Hus AB was one of the co-founders of the Swedish Green Building Council. The energy saving actions in the Natural Science Building has led to a certification as Green Building in 2010 (level Silver).

Finally costs were discussed. When discussing reasonable pay-off different periods are mentioned. Akademiska Hus AB Region North chose a pay-off period of maximum seven years, and many investments has been profitable since the energy reduction has been up to 80, 90 percent and the electric energy (including building electricity and operational electricity) has been reduced about 50 percent.

### **Discussion and conclusions**

In the reconstruction and re-building of the Natural Science Building at Campus Umeå conscious and courageous leadership is important for the will of innovation and for set up far-reaching goals, beyond legal requirements. An enthusiast, as the project leader, who had the ambition to create the most energy efficient building in the region, also seems to be important for the project's result.

The chosen installations does matter. The installations in the Natural Science Building has reduced the heat energy about 85 percent, and was in 2013 63 kWh/m<sup>2</sup>. This can be compared to today's Swedish Building Regulation that maximize the energy use to 120 kWh/m<sup>2</sup> and year. To succeed with a VAV-system where the least efficient device is setting the level for the whole system, a holistic plan for all installations is needed.

In the renovation the windows were not changed. They were changed to type 2+1 in 1991. Windows with lower U-value could have been chosen but the investment was considered neither viable nor sustainable at that time. However, since the insulation cassettes has a technical life time of approximately 20-25 years and modern insulation cassettes have improved, the investment should be profitable today, and also, a windows change is listed as an action in the planned maintenance in 2014. The façade has 100 mm of insulation and could theoretically be increased. Yet, the building has a façade made of bricks and would be difficult to insulate without re-constructing it completely. To insulate on the inside would decrease the rentable area. This solution was and still is considered non-profitable.

Lesson learned from the re-building of section B is also the benefit of emptying the section completely and to do a complete renovation. In reality, there is almost always tenants left in parts of the building since it can be difficult to evacuate large amount of students and employees for a long time.

Sustainability is a balance between saving energy, reducing costs and avoiding unnecessary waste. Maintaining buildings is a 'never ending project' and it is important to continue to work with small actions in a long term planning.

Finally, a conscious and courageous leadership as well as enthusiasts and ambitious goals seem to have played an important role when re-building and renovate the Natural Science Building at Campus Umeå. Maybe has the company's strategically work with sustainable development issues and their environmental management system also been a driving force. However, in the end, the pay-off periods and prices of energy seems to be decisive for the final choices.



## References

1. Swedish Energy Agency (2014). Energiläget i siffror 2013. [Energy in Sweden, facts and figures 2013] ET2013:22.
2. Lundberg, Ulrika (red.) (2012). Energieffektivisering – första steget till ett hållbart företagande. [Energy efficiency – first step towards sustainable entrepreneuring]. Luleå: Nenet
3. Veibäck, Ester (2007). Energianvändningen i skolor. [Energy use in schools]. Stockholm: Swedish Energy Agency. ISSN: 1403-1892.
4. Swedish Energy Agency (2007). STIL Inventeringar av kontor och förvaltningsbyggnader [Inventory of offices and administration premises] ER 2007:34. Stockholm: Swedish Energy Agency. ISSN 1403-1892
5. Swedish Energy Agency (2010) Energin i våra lokaler. STIL2. [Energy in our premises] ET2010:08.
6. Wagner and Llerena (2011). Eco-Innovation through Integration, Regulation and Cooperation: Comparative Insights from Case Studies in Three Manufacturing Sectors. Industry and Innovation, Vol. 18, No. 8, 747–764, November 2011.
7. Kenttä och Stenmark (2003). Förändringsarbete. Ledarens syn på lyckade och misslyckade förändringsarbeten. [The leaders view of successful and non-succesful change management] 2003:096SHU. Luleå: Luleå University of Technology. ISSN: 1404-5508
8. Lundholm och Åström (2012). Innovationskraft för hållbar utveckling [The power of innovations for sustainable development]. Luleå: The Natural Step.
9. Gauthier, J. and Wooldridge, B. (2012). Influences on Sustainable Innovation Adoption: Evidence from Leadership in Energy and Environmental Design. Business Strategy and the Environment. Bus. Strat. Env. 21, 98–110 (2012). Published online 20 May 2011 in Wiley Online Library. (wileyonlinelibrary.com) DOI: 10.1002/bse.716
10. Denti and Hemlin (2012). Leadership and innovation in organizations: a systematic review of factors that mediate or moderate the relationship. International Journal of Innovation Management. Vol. 16, No. 3 (June 2012) 1240007 (20 pages). Imperial College Press. DOI: 10.1142/S1363919612400075
11. Granberg, Roger (2014). Head of property management, Akademiska Hus AB Region North. 2014. Interview, 15th January, 2014.
12. Mattisson-Linnala, Sophia (red.) (2011) Lönsam energieffektivisering [Profitable energy efficiency]. Stockholm: Sabo. DOI: 13626 1000/2011-06
13. SFS 2009:907. *Förordning om miljöledningssystem i statliga myndigheter*. Västerås: Miljödepartementet.
14. SFS 2009:893. *Förordning om energieffektiviseringsåtgärder i statliga myndigheter*. Västerås: Näringsdepartementet.
15. Umeå University (2003). Miljöpolicy [Environmental policy]. Fastställd av universitetsstyrelsen 1996-03-11 och rev 1998-09-25 samt 2003-04-07 Dnr: UmU 102-949-03
16. Umeå University (2012) Vision 2020. Fastställd av universitetsstyrelsen 8 juni 2012. Dnr: UmU 100-394-12



## **The Preliminary model for the environmental oriental design of Kaohsiung Houses in Meinong**

### **Speakers:**

Huang, Chin-Ming<sup>1</sup>; Li, Yen-Yi<sup>2</sup>; Wu, Chia-Chi<sup>2</sup>; Yang, Po-Yuan<sup>3</sup>

<sup>1</sup> Kaohsiung City Government, Kaohsiung, TAIWAN

<sup>2</sup> GAID, ShuTe University, Kaohsiung, TAIWAN

<sup>3</sup> GAID, ShuTe University, Kaohsiung, TAIWAN

**Abstract:** *There were the actions of Kaohsiung city government to encourage the social participation and the environmental oriental living space to identify the Kaohsiung House. In this preliminary action for the Self-built environmental oriental designed Kaohsiung House was located in the area where most of the cultural livings in Meinong Township of Kaohsiung. The self-constructed method was adopted to create by the local residents in the past life experience and professionalism. In order to make a corresponding discussion again and view their relative potential difference, we try to demonstrate the possibility in drawing on environment and humanity reflected to the existing buildings and Kaohsiung house design principles. The demonstrated farmhouse was belonged to a senior high school teacher who devotes himself to practice the eco-lifestyle and try to follow the Kaohsiung House Actions. Therefore the site was selected in Meinong of his hometown with the base area is 600 m<sup>2</sup>, construction area of 160 m<sup>2</sup>, the proportion was 73% permeable pavement, native grass grown extensively in Eastern create ecological pond. The building was designed by three friends, one architect and with the help by ShuTe University. The house was constructed in major light steel structure for two levels and the double wall system was made in wood and bamboo grid with infilled clay wall. The outer cover is with wood rain edition panels. There were two natural ventilation towers and part of roof system is green roof with rain harvesting system for irrigation. The budget for the building is only 80,000 EURO and provides a natural and healthy living space. A POEM (post occupation evaluation method) measurement was adopted to verify the quality of house and recheck by the ten Kaohsiung House guidelines. The results show a good achievement for this kind of self-constructed with cultural and environmental oriental design. This project is now become the famous education center for the Kaohsiung House in Meinong.*

### ***Preliminary model test, self-constructed, environmental oriental design***

#### **Introduction**

The Kaohsiung city government start to push the Kaohsiung LOHAS House promotion from 2011. The ultimate goal of Kaohsiung is to transform from heavy industrial city into a healthy, sustainable and livable area in Taiwan. At the same time, the green building regulation in Taiwan still has some missing points rather than the efficiency indices, they are the environment and culture oriental characteristics by the spirits of living place. Meinong area is a unique township in Kaohsiung with the Hakka culture and good rural living atmosphere for a quality farm land area. Therefore the city government try to encourage the inhabitants of Kaohsiung to find out the real representative housing model for both new construction and renovating projects. This study was take one of the pilot projects in Meinong, and the house owner was the person who devote himself to create the local identification and try to keep the culture in this region. The planning and design criteria of



Kaohsiung LOHAS House was set as the verification items to review the achievement of this building, and this progress also can give the feedback information to the revise of criteria.

### **The selected preliminary house in Meinong**

The demonstrated farmhouse was belonged to a senior high school teacher who devotes himself to practice the eco-lifestyle and try to follow the Kaohsiung House Actions. Therefore the site was selected in Meinong of his hometown with the base area is 600 m<sup>2</sup>, construction area of 160 m<sup>2</sup>, the proportion was 73% permeable pavement, native grass grown extensively in Eastern create ecological pond. The building was designed by three friends, one architect and with the help by ShuTe University. The house was constructed in major light steel structure for two levels and the double wall system was made in wood and bamboo grid with infill clay inside, and the outer cover is with wood rain edition panels. There were two natural ventilation towers and part of roof system is green roof with rain harvesting system for irrigation. The budget for the building is only 80,000 EURO and provides a natural and healthy living space.

The building is constructed in wood, and the basic components of the RC concrete construction. From the ground base is self-made 1B brick wall from bottom to 100 centimeters heigh as the belt to prevent the moisture damage. The main structure is made by wood structures with the partition brick wall system to strengthen the structure for the earthquake. The roof is constructed by the timber closure system and the roof with the metal tile-like plate. The followings description is the detail. All the design and the construction are done by the houseowner with the academic team and the process is to hire the workers to finish together with the houseowner and students.

(1). A low wall base: 100 cm with 1B red brick piled high, low wall about 20 cm in height to install with a 25 high and 50 cm width switch blinds which give natural ventilation pressure and increase the low-level cooling air into house floor. Above 100 cm height is set the low wall surface to prevent the corrosion and soil moisture affect the main structure of the building.

(2). Wall Design: There are two construction methods to finish walls of the building. The firstone is red brick wall system, and another is plus lime mixed earth with clay surface to finish the wall. Red brick is mainly set in the partition wall of the house. To increase the weight of the roof bearing design, the outer wall of mud stirred fibrous material (rice straw, hemp, *etc.*) and then using lime substances smoothly finish the surface. The differences on materials and construction methods can be concluded by the loads and the corresponding environmental factors.





*Figure 1 the form of the preliminary model of Kaohsiung LOHAS house in Meinong*

(3). Pillars design: the pillar for the structure are took the used fir poles from the wire rod, and especially houseowner try to find local abandoned old fir utility poles to build the house. Because they are well-structured and are finished in corrosion resistance, they are good for the column structure of the house, in conjunction with ground-based and roof cladding interface.

(4). Window design: There are four differences of the opening height set. The lowest one is set in 20 cm height from the ground level as the lower opening with adjusted louvers for ventilation. The second level is the normal wood windows with transparency glass from the 100 cm height to 250 cm. The third is use for attic set from 280 cm height from ground to get the sunlight, and the last type is the high louver openings for the thermal buoyancy ventilation control.



*Figure 2 the hybrid natural ventilation design and the different types of openings*

(5). Roof design: The type of the roof is following the traditional “smoke house” to set the double roofs in two slopes, which can have good higher openings for the ventilation and enough height to prevent the heat accumulation effect from the ceiling. The construction materials were adopted on wood structure in the form of housing, with the shape of the outer layer of tiles painted steel. Although the traditional black tiles materials are adopted, but still keep its quaint traditional architectural impression.



(6). Outdoor space: the design of the building using eaves to create exterior around verandah. The form can create not only external shading and cooling effect for the building, but also outdoor spaces that can linger in the space with a fair share parking shed roof extends to establish linkage of a good connections. The square space following the tradition living style tried to create a channel for the external permeable pavement, and to set the half moon pond by Meinong traditional courtyard as building vestibule.

### Preliminary evaluation by Kaohsiung house planning and design principles

Kaohsiung house planning and design guidelines for a total of three core concepts formulated by the Kaohsiung City Government Works. The principle items contain ten design criteria, including environmental sustainability, reflected in the three core health and living in self-evident, and then divided into permeable base plate, effectively shade, green roofs, to import materials and technology, into the design of the image field, creating the courtyard space, human space universal design, appropriate use of space functions, environmental health materials, create effective ventilation openings, etc. Figure 3 shows the structure of ten major design principles for “Kaohsiung LOHAS House” which were drawn based on these four typical areas. The idea of the principles is to take advantage of the adequate sunlight and diverse landforms of Kaohsiung to create Kaohsiung-featured buildings and attract global attention of the local social customs and humanities of Kaohsiung.

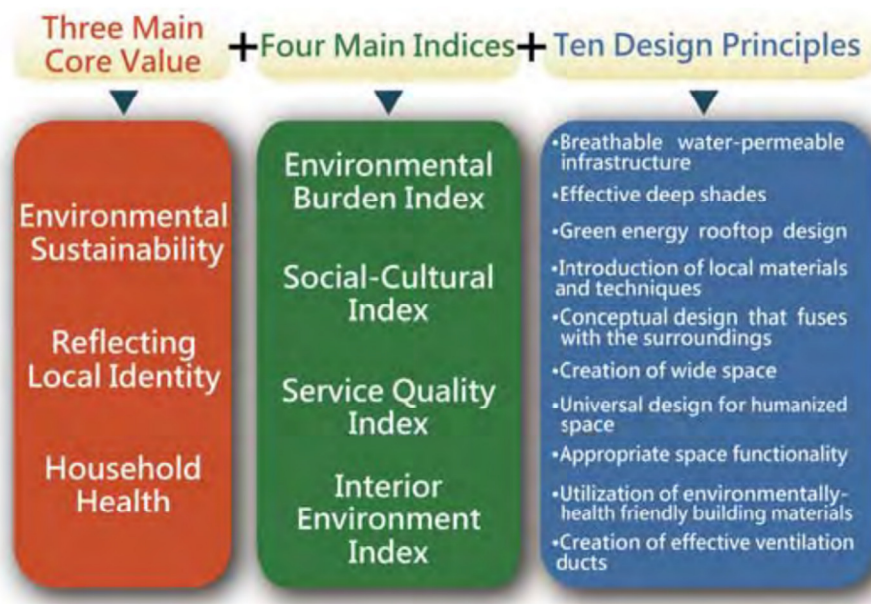


Figure 3 the principles of Kaohsiung LOHAS House

Therefore we use the ten principles to review this self-design and made house in Meinong. The achievement shows as followings:

(1). A breathing permeable infrastructure: The case building has more than 70% of the base plate for permeable pavement, and the purpose is to create a zone for thermostat, landscape retention and water permeability.



(2). Effective deep shade: This Meinong building modeled on traditional architecture, which not only designed and created a canopy-style verandah space, but also created an effective building exterior shading. And set in the west to the outer layer of wood windows enhanced activity window shade treatment, effective and flexible treatment of partial shade.

(3). In the introduction to materials and techniques: the use of red brick as a material in the key vocabulary in traditional architecture, the use of red brick building with white walls (adobe house white plaster) impression of traditional architecture and traditional building construction methods, white plaster part of the traditional plaster plus rice straw fiber material. The entries have to import materials and technology.

(4). Integrated into the field of Image Design: Meinong region retains the simplicity of rural landscape and cultural community, in this case the base of the building in addition to the return of the grass outside the building foundation to meet local landscape, interior decoration were also simple way to deal with the design, fully demonstrate the characteristics of the local environment.

(5). To create the courtyard space: The buildings do not have a balcony, terrace, in the outdoor environment with a canopy created by the cloister cohesion relationship building with the landscape between, although not as traditional courtyard houses as there are enclosed plastic atrium space, but there will be staying with the use of outdoor space reservation is still the courtyard space to create tactics.

(6). Human space universal design: space on the first floor of the partially processed universal design techniques, including moving lines smooth, smooth convergence to escape refuge space, entrances size ... and so on, but only the staircase leading to the second floor portion is provided, although the common armrest, but not for wheelchair access, is part of this project is relatively insufficient.

(7). Expedient use of space function: the case of resident population of 4 people, a living room space, a restaurant kitchen, a bathroom, three rooms, a living room, a spare space, the amount of space and function as quite reasonable, not too much or too large design, and fixed pattern Founder, some walls are still in the closet to use as an interior partition walls, is quite reasonable one.

(8). Building environmental health applications: the use of case material in red brick, stucco, wood, steel ... and even abandoned pillars also use fir poles, materials retain the original appearance, without superfluous decoration and painting modified, for the use of environmentally friendly building materials and healthy good case.

(9). Create effective ventilation openings: As stated previously, this case corresponds to local conditions sufficient window section, building orientation and fenestration amount, in addition to creating a normal station of the window opening is generally used, but also set the upper and lower louvers, but also on the transom activities designed to adjust the ventilation louvers, and each window has completely closed to use.



*permeable infrastructure*



*Effective deep shade*



*Local materials and skills*



*Integrated environment design*



*Healthy material*



*Effectively openings*

Figure 4 The review items by the principles of Kaohsiung LOHAS House

## Results and conclusions

During the study, we find the self-constructed single house in Meinong, was accepted by the inhabitants and it show a good consistency with the landscape of the place. The precess to build the house and the concept of the house is simple but easy to finish and maintain. The reuse concept help the houseowner save the money to finish the house, at the same time the student joined process which collaborated with university help the house to achieve the quality. After the review by the ten design guidelines, it shows a good consistency except the renewable energy roof and universal design. The reason is the budget and the house is unnecessary to use for disabled people.

From the point of view by the ten guidelines, this house shows a very good example to demonstrate the high quality Kaohsiung LOHAS house is not expand the cost to achieve the standard. The result also shows the social perspectives from the local society to accept this house as one part of the tradition, or transform from traditional concept with enough cultural repectives. The technology and methods of the house are easy to educate the people in this region to think about the house not only the modern building but also need to create the comfortable, healthy, cultural and sustainable building.

## References

*Green building autonomous regulations*,(2013), Kaohsiung city government, Taiwan

*Kaohsiung house planning and design criteria* ,(2013) , Kaohsiung City Government, Taiwan

Yoshiyuki Shimoda (2003), *Adaptation measures for climate change and the urban heat island in Japan's built environment*, *Building Research & Information* , 31(3–4), 222–230

## **A Post-Occupancy Evaluation Study of Traditional Shopping Street Reconstruction and Renovation — A Case Study of Sanfong Central Street in Kaohsiung, Taiwan**

### **Speakers:**

Yu-Jui, Lee

<sup>1</sup> Kao Yuan University, Kaohsiung City, *Taiwan*

**Abstract:** San Feng Zhong Jie (Sanfong Central Street) is located at the area between the north of Jianguo 3rd Road and the south of Trunk Railway Line in Taiwan. In order to let the whole Sanfong Central Street have a more systematic management, Kaohsiung City Government and Sanfong Business Promotion Association promoted a reconstruction and renovation project of the business district. One of the measures was to apply from the Ministry of Economic Affairs for professional operation techniques for Sanfong Central Street. Through professional counseling, the management system of the stores on the old street was strengthened; the street space was improved; drainage system was well-planned; sun and rain canopy was built; more exquisite and consistent signboards of stores were hung; and the street was paved with beautiful granite. As a result, and overall image of the business district was established. Furthermore, the quality of consumption was improved. Today Sanfong Central Street has become a commercial street with both cultural heritage and tourism value, which have increased the general business opportunities of the street. Several years after the renovation, just like any other plans, a gap is found between the integrated development and practical utilization of the street. There must be reexamination and evaluation made for subsequent utilization and re-positioning of the street. As for the effects appeared after renovation and the unexpected gap created after utilization upon completion of the original renovation plan, we should evaluate and explore the improvement methods, and after confirmation, reevaluate the substantial benefits. All these issues are the research area of the paper.

**Key words:** integrated development, evaluation of utilization

### **Introduction**

Located in Kaohsiung City, Sanfong Central Street is a collection and distribution center of large-scale purchases and sales of dried food, mainly wholesale and retail of a great variety of dried food. Ever since December 1999, Sanfong Central Street started accepting “Guidance for Business District Reconstruction and Renovation” offered by Department of Commerce, Ministry of Economic Affairs. In the aspect of hardware improvement, paving of ground, erection of entrance image, construction of rain canopy, light arrangement, and unified and exquisite signboards of stores were completed in 2000. After operation and utilization for over a decade, the facilities appeared to be damaged and old, and the environment became a little bit messy, planning and evaluation have to be done. Meanwhile, when the aspect of software is considered in times of evaluation, renovation also has to be made and supplemented to achieve reconstruction of the environment. Furthermore, through this study

and evaluation, the environment can become improved, and commercial behaviors can be more prosperous.

## **Research methods and procedure**

### **Questionnaire survey method**

Regarding the research method of the study, questionnaire survey and statistical analysis are employed:

Interviews of store owners: Understand the current utilization of stores before promotion of the Reconstruction Project and their environmental needs. Synthesize the actual environmental improvement items of store managers and store owners before the Project.

Questionnaire survey: Collect survey information of the degree of store and consumer satisfaction with the improved environmental facilities, and make quantitative statistics and analysis of different data.

Design of questionnaire: The questionnaire is divided into three parts. Part 1 is about satisfaction with façade system, building's environment and public facilities. Part 2 is about viewpoints of stores before and after change of the environment. Part 3 is about the basic information of interviewees, which are divided into stores and consumers.

## **Research methods and procedure**

### **Questionnaire survey method**

Regarding the research method of the study, questionnaire survey and statistical analysis are employed:





Interviews of store owners: Understand the current utilization of stores before promotion of the Reconstruction Project and their environmental needs. Synthesize the actual environmental improvement items of store managers and store owners before the Project.

Questionnaire survey: Collect survey information of the degree of store and consumer satisfaction with the improved environmental facilities, and make quantitative statistics and analysis of different data.

Design of questionnaire: The questionnaire is divided into three parts. Part 1 is about satisfaction with façade system, building's environment and public facilities. Part 2 is about viewpoints of stores before and after change of the environment. Part 3 is about the basic information of interviewees, which are divided into stores and consumers.



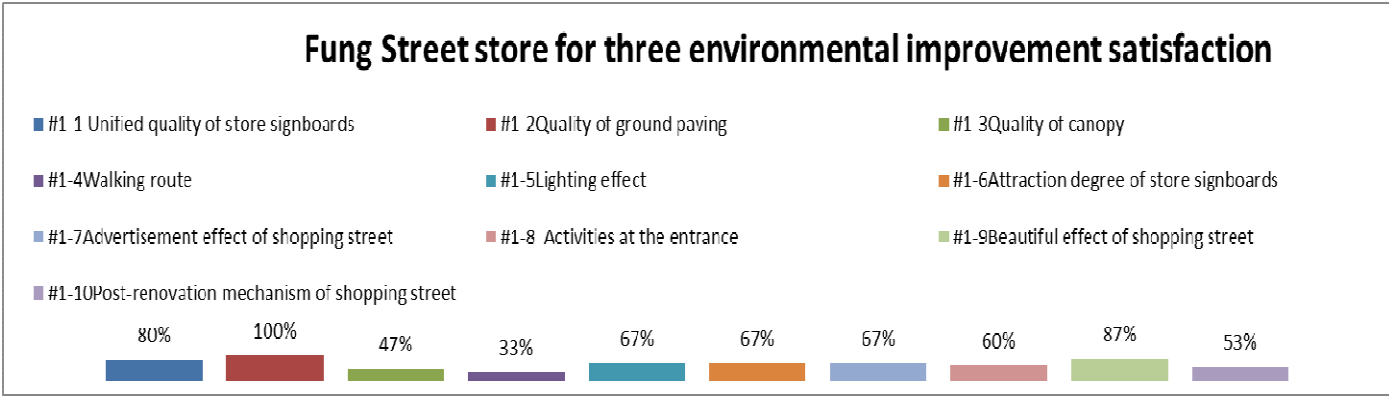
Field observation

Before improvement	After improvement
	
<p>1. Elements of the street were messy and disordered.</p> <p>2. Environmental quality of the shopping street was poor</p>	<p>1. Beautiful street scene, and pleasant shopping environment.</p> <p>2. Continuous arch-shaped roof frame extended forward, increasing the fun of shopping and effect of direction guiding.</p>
<p>6. The space of shopping street was improved. The sun and rain canopy was in transparent structure, improving the dark feeling the street gave, making the street space look taller, and increasing a pleasant feeling during shopping.</p>	
Before improvement	After improvement
	

<p>1. Store products needed to be shielded from sun and rain, so that store owners stretched their canopies without limit, making the environment look dark and low.</p> <p>2. The product display occupied road surface and lowered consumers' pleasant feeling during shopping.</p>	<p>1. The messy installation of canopies was improved, making the street space look taller, and increasing a pleasant feeling during shopping and walking.</p> <p>2. The product display area is fixed by facilities, making the shopping route widened, more pleasant and tidier, and increasing the capacity for visitors.</p>
---	--

### Issue of Reconstruction and Renovation Needs from the Stores of Sanfong Central Street

Rearranged contents of the issue of needs for store reconstruction and renovation on Sanfong Central Street			Main improvement for issue of needs
Issue of Needs	1	The facade of shopping street has to be built with an effect of landmark for the business district. The logo of shopping street has to possess characteristics of the shopping street.	Image of the entrance archway, effect of landmark
	2	For the sake of easier inspection, reparation and maintenance, the canopy materials should be practical and durable.	Durable, practical, easy for maintenance
	3	Integrating the lighting of shopping street and the environmental images of the street district.	Creation of shopping atmosphere
	4	Paving of ground should meet the requirements of slip resistance, beauty, safety of walking and flatness.	Slip-resistant stone materials, matched colors
	5	Outlook design, advertisements and signboards of stores should be unified, and meet the style of shopping street.	Exquisite and refined work
	6	Establishment of facilities for good-image advertisements of shopping street	Leave space for advertisements
	7	Street extension around the shopping street should match with the images nearby.	Street extension effect
	8	Build Mass Rapid Transit station, car park, bus stop and shuttle bus lines in the places around shopping street.	Solution of car parking problem
	9	Hold marketing advertisements and promotion activities to attract more visitors.	Attraction of visitors



**Method of interview**

The method of interview reflects the situation of the shopping street. The record of interview is made as follows:

Gradual decline of traditional shopping street: Due to successive appearance of large-size shopping malls, such as hypermarkets, fresh food supermarkets ... all of which were of similar nature, consumers gradually did not go shopping at traditional sales market, but changed to go shopping at large shopping malls with more pleasant environment and better facilities. And Sanfong Central Street, due to its messy environment, narrowness of street, and occupation of road area by some store owners for product display, gradually lost the shopping street’s advantage of “attractive to customer.”

The store owners expressed in the interviews that the maintenance, parking space, signboards and advertisements, characteristics of shopping street, and ventilation had to be strengthened or further reconstructed after improvement. Some store owners thought that under the circumstances that large shopping malls were established everywhere, the shopping street needed not only reconstruction, but also further aggressive actions. In the interviews with consumers, most of them thought that although the effects of reconstruction were not bad, there was insufficiency to be strengthened; and some consumers thought that they were dissatisfied with the reconstruction, but their dissatisfaction was at an acceptable extent, and believed that the cleanliness, characteristics and safety should be further strengthened and improved.

In the process of interviews, it was known that the store owners were dissatisfied with the signboards after improvement because they were mounted at wrong places, making consumers find the wrong stores when searching. Therefore, many store owners hoped that signboards could be further strengthened and improved.

Problem of “night lighting” was found from the field observation. Regarding the main effect of “bright, warm and pleasant lighting at night” out of night lighting facilities, the

degree of satisfaction was higher than the issue of needs by 0.5, and other items of the related needs also obviously appeared to have satisfactory effect. Therefore, through field observation, it was known that night lighting achieved a certain effect in both creation of atmosphere and beautification of environment. But in practical use, the foldable sun canopy was not folded up at night after daytime use, creating a destructive element to the lighting effect at night, obstructing the visual effect of the beautiful dome-shaped roof, and decreasing an opportunity for the environmental atmosphere to promote. Over this problem, several store owners were asked about the situation of the use. They expressed that it was very inconvenient for them to fold up and out the canopy.

Although “night lighting” has a rather high satisfaction, and its components and the facility itself are of no problem at all, only the use of the foldable sun canopy has weakened the night lighting effect. Therefore, users not only should know the importance of facility improvement, but also should fulfill their responsibilities in maintenance and management of facilities. Only with their cooperation can quality of the environment be completely enhanced

### **Conclusions and suggestions**

The overall statistical results are divided into two aspects: stores and consumers. And the aspect of stores is also divided into degree of satisfaction with environmental improvement and suggestion of outlook change; and so is the aspect of consumers. Focusing on the aspect of stores, the degree of satisfaction with environmental improvement is 6.5 in average. As to the degree of satisfaction with outlook change in future (Figure 3-3-1 ~ Figure 3-3-3), there are more diverse opinions among store owners. Anyway they all agree that the change of outlook and environment can increase economic effects. But they have no clear opinions on the messy, congested and bustling conditions of the shopping street. As long as there are measures that can facilitate economic effects and commercial activities, all the store owners support and agree to them.

According to the interviews at the site and the questionnaire results, it is known that both stores and consumers are satisfied with the paving of ground and unification of signboards. But there appear two extremes in their viewpoints on canopy. From the viewpoints of consumers, the average degree of their satisfaction with the overall environment is up to 60%. Of course consumers hope to see a bright, plain, safe and pleasant shopping environment. Currently, the degree of consumer satisfaction almost reaches 60%. But from the effective statistical data, we can still feel that consumers hope to see a brighter, more pleasant and safer shopping environment. Just because of this, consumers hold an optimistic attitude towards the change of the environment in future. Such an attitude of consumers towards the change of outlook and environment can be clearly seen from the statistical chart. Although Sanfong Central Street has undergone an overall reconstruction and change, and created a featured business district, both store owners and consumers expect that an adjustment or change for one more time can further provide the original shopping street with more convenient, brighter,

safer and more pleasant shopping environment. Meanwhile, they hope that some shortcomings appeared in the reconstruction for the first time can be improved, and want to see a more perfect shopping environment on Sanfong Central Street.

In the Reconstruction Project, the ground paving system will be flat, durable, and attached with water drainage facility. For the items with high expectation and low satisfaction, there appears a gap between supply and demand over the space utilization expected by the stores and the improvement measures proposed by the government departments. Right now there is still not a sound restriction standard and mechanism for facility utilization, maintenance and management on the shopping street. All facility problems are eliminated or collectively repaired by store owners themselves or shopping street managers.

### **Suggestions**

Consumers' suggestions for improvement of the messy and congested environment and the narrow passage are readjusted to serve as the main purposes of this study. According to the statistical data shown in, poor lighting and insufficient activities at the entrance should also be improved and strengthened again. As to the part of stores, it can be clearly seen from that sun canopy and walking route of pedestrians have to be further improved. As found in the interviews at the site and field observation, the problems of sun canopy are its poor ventilation and heat dissipation, creating sultriness in the air and unpleasant feeling to people there. In addition, rainwater comes in from both sides of the sun canopy, which totally has no effect of shield from rainwater. Therefore, it is suggested that the sun canopy's effect of shield from rain has to be reevaluated, and the overall ventilation of the shopping street has to be improved.





## Smart Interactive Buildings

### Speakers:

Arbizzani, Eugenio<sup>1</sup>; Civiero Paolo<sup>2</sup>; Clerici Maestosi Paola<sup>3</sup>

<sup>1</sup> Department of Pianificazione Design Tecnologia dell'Architettura, Sapienza University of Rome, Rome, Italy

<sup>2</sup> Department of Pianificazione Design Tecnologia dell'Architettura, Sapienza University of Rome, Rome, Italy

<sup>3</sup> Unità Tecnica Tecnologie Avanzate per l'Energia e l'Industria - ENEA, Bologna, Italy

**Abstract:** *The paper aims to validate innovative, competitive holistic concepts, tools for Smart Buildings, contributing to their large-scale penetration of the European market, policy and research.*

*The human aspect represents the central focus of Smart Building design not only to the technological definition of Smart Building concept but even to the definition of building type (social housing, schools, housing for elderly), whose diffusion within the city, linked with the concept of urban energy network, could drive more easily towards paradigm of Smart City.*

*A collaborative project management in the construction sector has become a prerequisite to develop Smart Buildings and buildings stock that are technically and economically optimized to Smart City paradigm. Design approaches have to move from a conventional linear process (from architect to engineering bureaus and construction contractors) to a more collective, yet iterative, approach which appears indispensable for an integrated systemic approach.*

**Key words:** *interactive nodes, open industrialized buildings, systemic approach, set of technical solutions*

### Smart cities, smart buildings

According to ongoing international discussions now and in the near future society is facing worldwide climate change; an effective low-carbon policy and highly efficient energy technologies in the very near future is needed. Dramatic CO<sub>2</sub> reductions, as outlined in the European Energy Roadmap 2050 (minus 80%, EC, COM(2011) 885/2) will have to be achieved in order to prevent the gradual increase in global average temperature caused by fossil fuel combustion. Thus, a change of the worldwide energy mix moving towards a smart integration of renewable energy sources (photovoltaic, geothermal, wind, biomass, etc.) into energy networks is of crucial importance for achieving the ambitious targets for CO<sub>2</sub> reduction. Based on this, reliance on imported fossil fuels could be decreased enormously leading to improved energy reliability in Europe in a long term vision. Nevertheless, according to the International Energy Agency (IEA) energy efficiency is one of the largest influencing factors for improving the critical situation of our environment. Despite the impressive growth in renewable energy in recent years, most of the world's energy needs and the increase in energy demand since 2000 are still met by fossil fuels. On a European scale,



only 10.3% of the gross final energy consumption in 2008 has been based on renewables. This is due to the fact that most renewables are not cost competitive under present market conditions and still rely on various forms of economic incentives within government programmes (IEA, 2010). Hence, policies and national strategies to facilitate the integration of variable renewable into our energy networks are crucial in order to reach the overall 20% target by 2020.

In addition to above described global environmental changes the urbanization of society is another major factor that has to be considered in the context of energy. According to the UNFPA State of World Population 2007 report, the majority of people worldwide are already living in urban areas or cities since the year 2008, which is referred to as the “tipping point”. Since about two thirds of the world’s energy is consumed in urban areas this has significant implications both for energy security and the global greenhouse-gas emissions bringing cities to the forefront of climate change actions. One of the key vehicles of the EU for accelerating the development of large scale deployment of low carbon technologies is the European Strategic Energy Technology Plan (SET Plan), within this European Industrial Initiatives (EII) as well as “Smart Cities and Communities Initiative” highlights the importance of intelligent energy management systems in cities in order to achieve massive reductions of greenhouse gas emissions by 2020 as outlined in the “20-20-20 targets” or the European Energy Roadmap 2050. The International Energy Agency (IEA) states that radical innovations are needed and an “energy revolution” has to be initiated together with dramatic changes in our attitude and investment priorities. This statement extended to strong need for “energy systems thinking” (IEA, 2012) highlighting the increased system complexity and the great diversity of energy technologies to be integrated in our built environments. To achieve these targets, the implementation of CO<sub>2</sub> saving measures shall be complemented by complex stakeholder processes and innovation concepts at city level involving all relevant partners in order to start the transformation of existing cities into “Smart Cities”, as complex structures involving a continuous interaction between the major parameters and components related to the entire energy system of a city. One important aspect of “Smart Cities” that has not been considered in the past is the switch from single technology applications to a multi technology perspective combined with energy management in order to make existing energy systems of urban areas more intelligent, as well as the “switch” from single buildings to plurality of buildings (district) as physical nodes for built environment; what fits to city level fits to building level, too: it is necessary to consider the switch from single building to district, from an integrated approach of building design to an holistic approach of it, to better link buildings to “energy systems thinking” required to move cities towards Smart Cities paradigm.

### **A systemic approach for Smart Building**

EEB or Energy Efficient Buildings make use of energy conservation measures and on site renewables to reduce their energy demand. Moving towards paradigm of Smart Cities where decentralized energy generations and highly interconnected urban infrastructures are in place, buildings become physical interactive nodes of larger networks which call for an upgrade of building models in direction of Smart Buildings. Both new construction and renovation of the



existing building stock are in the scope for Smart Buildings as enabler of development of European Smart Cities. New challenges arise from moving towards a paradigm of decentralized energy as optimized interactivity with real-time energy flows, climate, people, cultural heritage and urban networks.

The highly interdisciplinary character of planning still involves today a two-way relationship between the working reality of the building site, scientific research and industrial production, encouraging the creation of rapid performance in technological systems and high-quality product and smart solutions. The need to promote integrated and coordinated architectonic planning with a strong typological and technological connotation can only be satisfied through technical choices made according to logic of process, the result of a sharing of the knowledge and experience of each player involved. The building process is therefore a complex system of resources, constraints and procedures that must form a relationship with the innovations introduced by technological development in the productive sector. Today's fragmented nature of the construction chain still gives little freedom for innovations that are indispensable to shape a smart environment. Finally, as human aspect has to be the central focus of Smart Building design it would be necessary – from a research point of view – to focus not only to technological definition of Smart Building concept (open industrialized system) but even on that building type (social housing, schools, housing for elderly), whose diffusion within the city, linked with the concept of urban energy network, could drive more easily towards paradigm of Smart City. That's why a systemic approach for Smart Building need to focus not only on systemic approach at building scale (existing or new buildings) but even on understanding the technological definition of building as well as building type that, if spread all other the cities as physical “nodes”, would be able to accelerate the transition to Smart Cities.

### **Open buildings: nodes for smart city?**

To deliver the objective established under the LEIT Pillar of Horizon 2020 smart buildings are channelled towards a range of predominantly technology-related energy efficiency R&D topics, such as materials for building envelopes, self-inspection techniques and quality check measures, design tools (new construction and renovation at building and district level), integrated solutions for building and thermal energy storage for building applications. In this context most initiatives aim to contribute towards smart, sustainable and inclusive growth as on-site and nearby-generation of renewable energy for new buildings (electricity as well as heating and cooling generation, e.g. heat pumps, integrated photovoltaic, or other options) and the main objective is to accompanying energy efficiency measures to achieve standards higher than those of “nearly zero-energy” buildings. Different prototypes and pilot implementations in real industrial settings represent a clear added-value, as involve the participation of SMEs in the manufacture and installation of industrialized modules but to make these new, cleaner, low-carbon, efficient energy sources commercially attractive on the scale needed, research and innovation must be combined with measures facilitating the market uptake of these energy technologies and services. Industrialized and prefabricated



components are even more commonly used in the construction sector both in the renovation market and in the new buildings production, and are even more linked to evolved computer design tools. Compared to traditional construction processes, the production of open industrialized building represents the most effective response to a reduction in building costs and times on site to ensure the environmental and economic sustainability of the intervention without compromising quality and simplifying the installation/dismantling/re-use of components. Building components could, when relevant, be prefabricated in factories to reduce construction time, to improve on-site health and safety, and to reduce the embodied energy of the building.

Many definitions of the Smart City focus almost exclusively on the fundamental role of ICT in linking city-wide services. Some of the ICT technologies have an even broader context for future new or refurbished buildings and districts: new sensors can help check intermediate performance steps before commissioning (e.g. blower-door test in combination with thermal imaging for air tightness). The vision of these devices includes growing embedded intelligence for instance product and repair information. New field integration process with more detailed internal performance control following elementary construction steps and sensor networks represent key components not only as standalone devices, but also embedded in smart Energy Consuming and Producing Products [EupP]. In this way, the Smart Building systematically makes use of ICTs to turn its surplus into resources, promotes integrated and multi-functional solutions, and improves its level of connectedness. From the technological perspective, the biggest challenge is to re-engineer existing technologies and to develop new ones which are able to function together in systems. A particular set of solution in field of smart building is represented by the technical solutions that concern not only the main sub-systems of the building but also power and lighting management including smart plugs, light sensors and power management automation software. Regarding the new construction, materials and energy equipment integration already allow reaching very low energy demand. Yet, the investment costs have to be further reduced while taking care of several other design constraints need to be improved by smart solutions and typological adaptation. The transition of these innovations from different contexts or sector may contribute to the integration of components and sub-systems to reduce construction costs and risks in the future, and finally to promote energy efficiency of buildings and districts and the quality of the built environment. This is particularly adapted also to refurbishment, where parts of the new envelope can be pre-assembled off-site. Prefabricated parts can be monitored in combination with a Building Information Model so that their location and guidelines for integration and installation are available to all the parties involved, as to assist workers in reducing time to deploy or increasing quality standards. Different innovations are nowadays available to bridge this context and collaborative platforms for concurrent building engineering (design, construction, commissioning, service life, refurbishment, end of life) provide various systemic approach as: design tools involving a dynamic multi criteria based on an integrated design for technological and typological features (e.g. thermal, visual and acoustic comfort for each building typology); tools to model/control buildings during the life time.



A systemic approach make possible a visualization of the criteria that each spatial and technical solution must fulfill in order to be recommended for a given building typology; a set of technical solutions could be determined for the single building level to respond to specific quality requirements (e.g. Energy Performance, Indoor Environmental Quality, Life cycle aspects) and to typological features (e.g. functional usage), basing the knowledge on a specific Integrated Design and on the overall strategies of the different building labeling schemes or assessment tools that already exist. Different assessment systems aim at building optimization in the planning stage, and are based on the analysis of the building as a whole, where functional services are defined as Building elements (private and shared/public spaces) depending by the use of the building and the technical sub-systems are classified on the basis of the construction method (e.g. dry/wet) and materials as Sub-components assembled (structure, external wall, roof, etc.). They include criteria and goal catalogue, which defines requirements for sustainable buildings, and the procedure for assessing and receiving an energy performance certificate. This evolution, because of a modification in the cultural context, has been possible also for an improved flexibility of the industrialized production that guarantees the integration of different solutions with other technological sub-systems. In this context the last design approach in the social housing scheme has been a real driver for sustainable buildings in the residential sector, and now, because of the new generation of prefabrication, the use of modular design components represents a very promising tool for developers which can make sure their decision making tool and the related study types will be useful and used by designers, construction companies or labeling assessors.

Within the range of initiatives of procedural and constructive experimentation on the theme of housing, CCCabita - Environment Conscious Buildings Systems - represents an open industrialized smart building system with a strong typological and technological modularity. The system is the result of an integrated interdisciplinary know-how of operational synergies deriving by SMEs (small and medium enterprises) that are involved in the project and various players and scholars gathered in a single consortium. From the point of view of the typological-distributive plant, the planning approach is based on the search for different models of settlement able to represent the best synthesis between tradition and innovation through solutions that meet the expectations of a wide variety of buildings (e.g. school and residential buildings) and of users, following the logic in place in the demographic and compositional structure of households (young couples, single people, large families, halls of residence, self-sufficient disabled, elderly, students). Aligned with the revised common objectives of the EU Strategy to combat poverty and social exclusion, pilot projects include targeting this high risk for vulnerable and low income groups as elderly, ethnic communities and migrants. The perspective arising from this vulnerability is reflected in a varied set of housing problems and promotes policy responses and a new project strategy that aim to provide access to decent and affordable housing for all in these communities which are socially, economically and environmentally sustainable. The importance of this issue led to the commissioning of a study that, moving from the concept of social housing to the new standard of the decent housing, targets a different technical standard for public housing, as





was introduced in 2000 by the United Kingdom government to provide a minimum standard of decency of housing conditions for all those who are housed in the public sector (e.g. council housing and housing associations), in full respect of each countries choices to deliver the best for citizen. A decent home – leaving the lack of a common meaning at a European level – represents a living solution which meets modern standards of fitness, structure, energy efficiency and facilities, and involves design strategies both for new and for existing buildings. In this context the decent Housing has a key role in promoting community up to standard and meet new design alternatives (e.g. common laundry, co-housing, etc.) to enhance community cohesion, to contribute to the creation of more stable, safer neighborhoods and, on the other hand, respecting the rights of people who choose to live in either single identity or integrated neighborhoods.

### **Conclusion**

Traditionally the building industry is divided in different layers. The professionals and trade responsibilities are divided usually in four groups (architectural, structural, mechanical electrical) following all the building design phases. The results of the lack of integration between that kinds of layers is a functional gap all over the building process. The building delivery process is usually divided in seven sub sequential layers (in order: preliminary design, detail design, working drawings and specs, tender (bidding) – offer, planning and scheduling, construction operations, commissioning). In this case there is a management discontinuity all over the building process (operational islands). During every phase of construction each professional and trade responsibility is combined with building delivery process. So in this case the problem is the lack of coordination and communication between function and along the phases. Energy-efficient buildings make use of energy conservation measures and on-site renewables to reduce their energy demand; then new challenges arise from moving towards Smart Cities paradigm. Yet, collaborative project management in the construction sector has become a prerequisite to develop a building stock that is technically and economically optimized: this goes against centuries of working habits. Design of Smart Building will involve all stakeholders within a collaborative approach, allowing for more iterative step. Design approaches have to move from a conventional linear process (from architect to engineering bureaus and construction contractors) to a more collective, yet iterative, approach which appears indispensable for an integrated systemic approach. Collaborative design implies shared data, practices and tools with proper training and education as a knowledge-based approach to collaborative design, allows designers accessing the right information and provides performance of real case, thanks to interoperable data base to manage economic assessment, BIM tools (cost effective and interoperable), harmonized LCA methods at the whole building and up to district scale. The necessary shift in mindset requires innovation in education and training practices to foster collaboration between architects, engineers and constructor for a “smart design”, as “smart design” is required to ensure performance of Smart Building in Smart city.



## References

ANCE (2012). L'industria delle costruzioni verso Horizon 2020. Una strategia nazionale, ANCE, Roma.

ANCI (2013). Vademecum per le città intelligenti. Edizioni Forum PA

Annunziato, M. (2011). Smart city: una strada possibile per le città sostenibili. *Energia, ambiente ed Innovazione*, luglio/ottobre, Edizioni ENEA.

Arbizzani, E. (2012). Filiera produttiva e tecnologie innovative per l'abitare. *Techne*, Vol. 4, Firenze University Press.

Arbizzani, E., Civiero, P. (2013). Technical solutions and industrialized construction systems for advanced sustainable buildings. In: Bragança, L. et al. (ed.). Portugal SB13. Contribution of Sustainable Building to meet EU 20-20-20 target, Multicomp Ed.

Civiero, P. (2013). Sistemi costruttivi aperti. *Ponte. Mensile di Progettazione, Gestione e Tecnica per Costruire*. Vol. 4, DEI -Tipografia del Genio Civile.

Clerici Maestosi, P. (2012). Human oriented technology per l'ecosistema urbano. *PROTECTA: ambiente, tecnologia e sviluppo sostenibile*. Aprile. Ecoedizioni Internazionali,

Clerici Maestosi, P. (2012). *Functional recovery in urban industrial area. Methods and tools to integrate efficiency and sustainability in the pre-design phase*. Atti del Convegno Sustainable Cities 2012, Ancona.

Clerici Maestosi, P. (2012). *Smart Building, Smart laboratories: a decision support tool for planning phase*. Atti del Convegno Smart City Exhibition, Bologna.

Clerici Maestosi, P. (2013). *La politica dell'Unione Europea per le attività di Ricerca e Sviluppo in ambito urbano*. Atti del Convegno Smart City Exhibition, Bologna.

Dohler, M. et al. (2013). *Smart cities*. IEEE Communications Magazine 51, no.6, Guest Editorial.

European Parliament (2014). Mapping Smart Cities in the EU, Doi: 10.2861/3408. Publication Office.

European Commission (2012). Strategy for the sustainable competitiveness of the construction sector and its enterprises, COM 2012-433 final, Brussels.

Forghieri, C., Mochi Sismondi, A. (2013). Il paradigma Smart City. Verso SMART City Exhibition 2013, Edizioni Forum PA.

Giffinger, R. et al. (2007). Smart Cities: Ranking of European medium-sized cities. Granelli, A. (2012). *Città intelligenti? per una via italiana alle Smart Cities*. Luca Sossella Editore.

## **Architectural Implications in the Building Integration of Photovoltaic and Solar Thermal systems – Introduction of a taxonomy and evaluation methodology**

### **Speakers:**

Vassiliades, C.<sup>1</sup>; Savvides, A.<sup>2</sup>; Michael, A.<sup>3</sup>

<sup>1</sup> University of Cyprus, Nicosia, Cyprus

<sup>2</sup> University of Cyprus, Nicosia, Cyprus

<sup>3</sup> University of Cyprus, Nicosia, Cyprus

**Abstract:** *This paper examines the architectural implications for the integration of photovoltaic and solar thermal systems in new construction or extensive renovation of existing building shells. The study is based on a documentation of the current literature and a taxonomy of current and proposed applications based on conformance to a variety of building typologies. Additionally to the literature review, the paper delves on the investigation, assessment and categorization of existing applications, through case studies, analyzing the type and the function of each case, in order to identify the best practices for the different applications. The ultimate aim of this effort is to critically present the breadth of typologies of the plethora of alternatives available for building integrated photovoltaic and solar-thermal panels in ways that maximize their potential for solar gains for the purpose of addressing the power and thermal requirements of a given structure as well as its design.*

**Keywords:** *Active Solar Systems, BIPV, BISTS, Building Envelope, Façade Design*

### **1. Introduction**

The energy problem is at the forefront of current discussions. After the first oil crisis in the early seventies, the use of renewable sources, especially solar energy integrated with architectural design, is an important parameter in reducing a building's carbon footprint [1]. Also, as the stock of fossil fuels is depleted, countries like Cyprus look to exploit local climatic conditions – extended sunlight periods – to lessen reliance of the current building stock on the national grid which relies on fossil fuel combustion. Indeed, solar energy is viewed as one of the main alternative sources of energy to deal with fossil fuel dependency [2], especially as the operational costs of buildings account for 40% of energy use in the EU context. The increasing use of renewable energy sources means that building integrated solar thermal systems (STSs) and photovoltaics (PVs) have a key role in the provision of electricity, domestic hot water and in the heating and cooling of buildings [3].

### **2. Methodology of Investigation**

The proposed methodology relies on literature review and precedent analysis to formulate a classification and taxonomy of various existing applications of the above mentioned systems. The forty-two case studies selected and featuring both BIPV and BISTS, provide a sample for a taxonomy that delves on the investigation, assessment and categorization of existing system applications. In each case, system functions are examined in order to identify the specifications of the various applications and juxtapose them in a table format according to

new buildings and extensive renovations. PVs and STSs are dealt in parallel to provide a holistic approach to an evaluation of the architectural implications building integration.

### 3. Literature Review

In the literature, the debate on renovation of existing buildings is dominant, with the field of building integrated technologies moving in that direction – the integration of solar panels to existing buildings in order to produce energy required for the building's operation without occupying any land. In the ongoing discussion, PVs are seen to be generally of benign environmental impact making use of one of the most viable renewable energy technologies by replacing existing building cladding materials [4].

Consequently, it is important to define the geometry and performance of BISTS and BIPV and to examine their applicability to new or existing building shells. Identified systems may fall into the following groups: *BIPV foil products*, *BIPV tile products*, *BIPV module products* and *solar cell glazing products* [5]. The STSs available for integration in the market are: the *Glazed Flat Plate Hydraulic Collectors*, the *Unglazed Flat Plate Hydraulic Collectors*, the *Unglazed Plastic Hydraulic Collectors*, the *Unglazed Flat Plate Air Collectors*, the *Vacuum Tube Hydraulic Collectors* and the *Concentrating Hydraulic Collectors* [6]. These technologies take the solar irradiation and convert it into solar thermal energy -for air or water heating- in the case of BISTS [7] and electricity in the case of BIPV.

Moreover, to be considered as **building integrated** these systems should be a functional part of a building's structure or should be architecturally integrated into its design [8]. The same rules, apply on the BISTS as well, having in mind that the basic solar thermal panel has the same geometry. The two usual **positioning locations** for a PV or an STS system are the roof and facade, with all other locations being known as building components [9, 10]. Another important aspect of these systems is the **flexibility** in the application of these systems to allow a multitude of building integrated options, e.g. BIPV foil products which are lightweight, flexible and can be curved, as well as being easy to install given prevailing weight constraints for roofs [5]. **Transparency** of the modules also offers the designer a range of possibilities to combine the production of electricity with interesting lighting effects [11]. **Weather proofing** is another consideration in the integration of PVs and STSs acting as the shell of the building as rainscreens or roofs. In this case the system modules act as an outer screen for the building, protecting an inner leaf from the deleterious effects of heavy wetting, solar radiation and the effects of thermal expansion and contraction [11]. It is also important to consider the effect of **noise reduction** as the system panels in double-skin facades or vertical flat surfaces make a positive contribution in this aspect [12, 13]. Also, by **shading** a façade system panels provide a passive way to limit excessive solar gains and the good opportunities of the combination of system modules into shading devices, gives both reduced cooling loads and utilization of solar energy which are a palpable expression of the conservation of energy [11]. Further, designers may vary the **color and texture** of an STS absorber without affecting to a large extent its performance (7-18% in similar climatic regions with Cyprus) [14] or in the case of the PVs more colors can be obtained by the variation of the thickness of the anti-reflection



coating, although by doing this, the efficiency will decrease by 15–30% depending on the color, due to the increase of the overall reflection [11]. The parameters outlined above may be incorporated in **pre-fabricated** and **customized units** and PV and STS modules -especially the flat-ones- may be used as "filling" panels, integrated into **curtain wall** systems or **double facade** systems either in the vision area or in the spandrel area of the facade [11].

### 3. Comparative assessment and Critical Evaluation of Building Integrated Systems.

#### 3.1. Best Practices

In order to cover all the possible applications regarding building integrated PV and ST systems, 42 case studies were examined. In these case studies, 7 types of different technologies are applied on new or existing buildings. Some technologies are more "popular" while others are seen in a limited number of examples. Various types are listed below:

##### 3.1.1. BIPV and BISTS in New Buildings.

In this case, building integrated solar thermal systems and photovoltaics are fully integrated into the shell and form an integral part of the building design concept (Figure 1).



Figure 1: Views of integrated systems in 4 newly constructed buildings [Available online from [www.biotechnology.net](http://www.biotechnology.net), [www.fondazionerenzopiano.org](http://www.fondazionerenzopiano.org), [www.jetsongreen.com](http://www.jetsongreen.com), [www.archdaily.com](http://www.archdaily.com) (accessed 25 May 2014)]

##### 3.1.2. BIPV and BISTS in Existing Buildings.

Similarly, there are examples of applications in renovated buildings which form part of the building envelope, while improving the building's energy performance (Figure 2).



Figure 2: Views of integrated systems of 4 renovated buildings [Available online from [www.projects.pilkington.com](http://www.projects.pilkington.com), [www.solarwall.com](http://www.solarwall.com), [www.ecda.co.uk](http://www.ecda.co.uk) (accessed 25 May 2014)]



### 3.2. Comparison in the application of BIPV and BISTS in new and existing buildings.

The organization of the table below (Table 1) is based on the differentiation of these two categories, which thereafter, are organized according to the system technologies mentioned

			Applicability on New Buildings							Applicability on Existing buildings						
			BIPV				BISTS			BIPV			BISTS			
			Modules	Solar Cell Glazing	Foil	Tiles	Unglazed Flat Plate Air Collectors	Unglazed Flat Plate Hydraulic Collectors	Vacuum tube hydraulic collectors	Modules	Solar Cell Glazing	Foil	Tiles	Unglazed Flat Plate Air Collectors	Unglazed Flat Plate Hydraulic Collectors	Vacuum tube hydraulic collectors
System	Application	Air Heating					16							16		
		Water Heating						4	1						4	1
		Electricity Production	5	13	1	2				5	12	1	2			
Architectural	Application	Replacement of a building component	3	12		2		4		3	12		2		3	
		On Façade	3	9			16	2	1	3	8			16	1	1
		On Roof	4	4	1	2		1	1	4	4	1	2			1
		On Building Component		1				2			1				2	
		Flexibility														
		Ease on application														
	Building Physics	Transparency														
		Thermal Insulation		2							2					
		Weather proofing	5	11		2		2		5	11		2		1	
		Noise Reduction	3	3			16	1		3	2			16	1	
		Shading	2	12				3	1	2	11				3	1
		Structural														
	Integration	Visible Collector Profile	5	5				1		5	5				1	
		Surface Colour Texture		1		1	16	1			1		1	16		
	Construction	Pre - Fabricated Units	5	8		2		1		5	8		2		1	
		Customised Design		5	1		16	3	1		4	1		16	2	1
		Curtain Wall	2	3						2	3					
		Double Envelope Structure		3			16	1			2			16	1	
1								16		Low					High	

Table 1 - Comparative table between the application of BIPV and BISTS in new and existing buildings.

above. Subsequently, each system is examined according to its architectural integration merits, such as a system's integration on the building shell, e.g. on the roof, in a façade or as part of another building integrated component. Then, issues of system flexibility are covered both in terms of unit geometry and mounting ease – rated from low to high – both of which affect the viability of a system's integration on new or existing buildings.

Subsequent categories include architectural aspects, beginning with "transparency", which is rated again from low to high and addresses the extent to which system panels allow for effective insolation from the outside and visibility from the inside of a building façade. Thermal insulation is also examined, which addresses the "weather proofing" performance of the system panels constituting the building shell, which indicates the technologies that can provide protection from the weather to the building and also illustrate contributions with regards to noise protection and façade shading. There follows an estimate with regards to the shell structural system contribution inherent in the panel assembly, as a result of its integration in the building façade. Two further issues are examined: the extent to which the "collector profile is visible" after building integration; and the variations in "surface color or texture" beyond the base case. Next, the comparative table looks at issues of pre-fabrication and the customization potential of the systems examined in order to fulfill individual case study specifications; and lastly it indicates whether the system examined forms part of a curtain wall or double-skin facade.

### 3.2.1. Reijenga Classification

In the context of the discussion above, it is also important to quote the work of Tjerk H. Reijenga [9], on the integration of PV systems in architecture and their subdivision into five categories: 1. applied invisibly; 2. added to the design; 3. adding to the architectural image; 4. determining architectural image; and 5. leading to new architectural concepts. However it must be said, that the challenge for architects, is the proper PV modules building integration, and it must be noted that the invisible apply of PV modules to a project does not necessarily mean that this project has lesser quality [9]. So based on the findings of the preceding heading, the 42 selected case studies may be reclassified and organized according to Reijenga's classification as follows in Table 2:

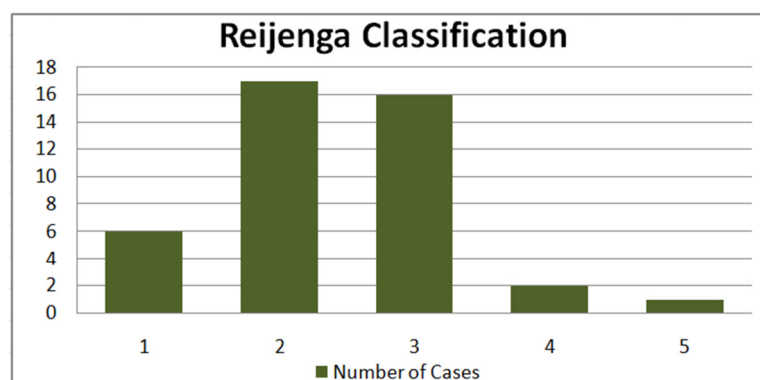


Table 2 - Dominant trends with regards to the integration of PV and STS in new and existing buildings.

## 4. Discussion – Conclusion

The results above indicate that building integration is equally possible in new and existing buildings. Also, the comparison reveals that the most popular method for integration is BISTS with the Unglazed Flat Plate Air Collectors, followed by BIPV technology of Solar Cell Glazing. Another important finding is that in a majority of the selected case studies, a number



of compatible building façade components are readily interchangeable with solar panels indicating the relative ease of integration, while at the same time weather proofing, noise reduction and shading are also significant. An important characteristic of a properly integrated technology has also emerged, in the ability of the Unglazed Flat Plate Air Collectors to be colorized. In relation to the construction of an integrated system, apart from the Unglazed Flat Plate Air Collectors, construction methods available do not determine the popularity of appropriate integration. On the other hand, it is significant that technologies which can be applied easily are not popular. It is also remarkable that no technology offers high system panel transparency, both in their application to new or existing buildings. It is also shown that although foil is flexible and relatively easy to apply, it is not a popular application. Finally, it is clear that no technology yet makes significant contributions to a building's structure.

In both cases of existing and new buildings, the two technologies that offer themselves for building integration are the BIPV, Solar Cell Glazing and the BISTS, Unglazed Flat Plate Air Collectors. Although they are not the easiest to integrate within a building facade, they are widely used due to their superiority in many of the categories illustrated above. However, it is significant that in the case of Cyprus, where cooling loads are about six times larger than the heating loads [15] - probably also true of several other Mediterranean locales - the preferred technology is Solar Cell Glazing, due to the shading it offers, which can be used as part of a passive cooling strategy. Electricity generation may then be used as an energy source for cooling. Similarly BISTS contribute to the production of hot air or water. Finally, the utilization of the reijenga classification analysis indicates that according to that categorization method the prevailing entries were the panel systems: "Added to the design" and also "Adding to the architectural image". From this to occur, system panel designs need to be innovative in the way in which they allow for it to coexist symbiotically and be part of the architectural concept of each building.

#### 4.1. Further Research

Given the results of this research, future work will be carried out in terms of prototyping of various assemblies of building integrated solar systems based on the parameters outlined above. The prototyping phase will be concurrent with a simulation phase that will attempt to examine the combination of parameters available to the design team, as well as the construction of scaled versions of building shell versions in order to conduct field measurements and for simulation model verification purposes on the road to a holistic approach with regards to the examination of the architectural implications in the Building integration of photovoltaic and solar thermal systems in the case of Cyprus.

#### 5. References

- [1] Tombazis, A. N. (1994). Architectural design: A multifaceted approach. *Renewable energy*, 5(5), 893-899.
- [2] Yang, Y., Wang, Q., Xiu, D., Zhao, Z., & Sun, Q. (2013). A building integrated solar collector: All-ceramic solar collector. *Energy and Buildings*, 62, 15-17.



- [3] Kalogirou, S. A. (2013). Building integration of solar renewable energy systems towards zero or nearly zero energy buildings. *International Journal of Low-Carbon Technologies*, ctt071.
- [4] Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy*, 33(3), 289-296.
- [5] Jelle, B. P., & Breivik, C. (2012). State-of-the-art building integrated photovoltaics. *Energy Procedia*, 20, 68-77.
- [6] Munari Probst, M., & Roecker, C. (2007). Towards an improved architectural quality of building integrated solar thermal systems (BIST). *Solar Energy*, 81(9), 1104-1116.
- [7] Probst, M. C. M., & Roecker, C. (2011). *Architectural integration and design of solar thermal systems*. Lausanne. EPFL Press
- [8] Peng, C., Huang, Y., & Wu, Z. (2011). Building-integrated photovoltaics (BIPV) in architectural design in China. *Energy and Buildings*, 43(12), 3592-3598.
- [9] Reijenga, T. H. (2003). PV in architecture. In: *Handbook of Photovoltaic Science and Engineering*. A. Luque and S. Hegedus (eds.). Chichester. Wiley
- [10] Gajbert, H. (2008). Solar thermal energy systems for building integration. *Licentiate Dissertation, University of Lund, Sweden, 2008*.
- [11] Roberts, S., & Guariento, N. (2009). *Building integrated photovoltaics: a handbook*. Basel. Walter de Gruyter
- [12] Scholes, W. E., & Sargent, J. W. (1971). Designing against noise from road traffic. *Applied Acoustics*, 4(3), 203-234.
- [13] Arons, D. M. (2000). Properties and applications of double-skin building facades. *Thesis (S.M.), Massachusetts Institute of Technology, Boston, 2000*.
- [14] Kalogirou, S., Tripanagnostopoulos, Y., & Souliotis, M. (2005). Performance of solar systems employing collectors with colored absorber. *Energy and buildings*, 37(8), 824-835.
- [15] Florides, G. A., Kalogirou, S. A., Tassou, S. A., & Wrobel, L. C. (2002). Modelling and simulation of an absorption solar cooling system for Cyprus. *Solar Energy*, 72(1), 43-51.

## Grid Electricity Demand Reduction through Applying Active Strategies in Baghdad-Iraq

### Speakers:

Al - Badri, Nadia <sup>1</sup>; Abu Hijleh, Bassam <sup>2</sup>

<sup>1</sup> Universtiy of Sharjah, Sharjah, United Arab Emirates

<sup>2</sup> Britishi Universtiy in Dubai, Dubai, United Arab Emirates

**Abstract:** *This paper is investigating the electricity demand reduction due to the use of active strategies for typical house in Baghdad. The motive was to reduce depending of the national electricity grid which is not reliable and suffers frequent daily interruptions. Simulation methodology was used to carry out this study using IES-VE software to model the energy consumption, calculate, and evaluate the power consumption and energy saving. The study covered the following parameters: coefficient performance of air-conditioning systems, solar domestic hot water, and photovoltaic panels.*

*The study covered different scenarios to arrive at the optimize case for each parameters in order to highlighted their effect on the energy saving, the result collected from all the simulations were categorized according to each parameter. The result indicates potential energy saving up to 39.1% for the optimized configurations.*

**Keywords,** *Active strategies, energy saving, IES simulation*

### 1. Introduction

A great interest has been growing among engineers and architects to design and create intelligent buildings. According to Ochoa and Capeluto [1] the active strategies are the active features or elements which are designed or added to the building to be self-adjusted to changes initiated by their internal or external environment. These strategies enhance the design of the building to achieve the thermal comfort conditions while reducing energy consumption. Silva et al [2] noted that "intelligent building" has become important infrastructures to minimize the operation cost of the building and provide comfort and safety for the occupant. Al Naser [3] found that the (GCC) countries have enormous solar power that can reach approximately (500-600 W/m<sup>2</sup>) for each Km<sup>2</sup> of land annually. In other words, this amount of solar energy is equivalent to 1.5 million barrels of crude oil. The integration of the solar DHW with PV and the building structure are the main way for solving the energy problems of the future. Ochoa and Capeluto [1] believed that the combination of active features and optimized passive strategies during designing buildings can achieve a savings of about 50 - 55% for most cases. the passive strategies have been investigated in a pervious research published in SB13 Al Badri & Abu Hijlah [4]. The paper covered many passive strategies including shading devices and insulation materials through reducing the U-Values of roofs, walls. In addition, the study examines different solar heat gain coefficient (SHGC) of glazing system. The outcome of using passive strategies shows



that the most affected parameter is the roof insulation whileThe second effect factor is wall insulation. The results of adopting a glazing system could vary from one project to another in relation to the ratio of openings to walls. However, it was found that by using shading devices, the impact on energy consumption was the minimum. Overall, the passive strategies combined can achieve 8.3% energy demand reduction.The study focuses on the solar energy in two types of implementation; Coffiecnt of preformance COP of the airconditioning system, Solar Domestic Water Heat SDWH, and Photvolitic Panels (PV)

## 2. PARAMETRIC STUDY

According to International- Agency [5] information and analysis Unit (IAU) reported in July 2010 for UN that households were receiving just eight hours of electricity per day in 2007.The United Nations Development Program (UNDP)[6] noted that the electricity supply has been deteriorated in some area especially Baghdad. According to Ministry of Electricity, Iraq is generating 8,000 megawatts only while the currently required power is rising to 13-15,000 megawatts. Since 2003 the public approval of the electricity demand has never records over 39% even during low demand periods[5].Observations done by the author in July 2012 associated with the facts that have been mentioned above create the outline of the problems which are highlighted as follows:

- Electrical power disconnects for several hours daily
- Private electricity generators are located between the residential zones and operated by unprofessional labourers as shown in Figure 1
- Electricity connection cables have been added randomly without any level of safety and secure, although, many families depend on these private generators, the amount of providing energy is very limited and it could not cover the actual demand of each house
- Almost every house should apply a converter to switch from the grid electricity to the private generators. This device could be damaged continuously and should be replaced by another one which cost money and effort.

Many Iraqi families could not apply the electricity for their houses because of the lower income



*Figure1. Private electricity generator in the middle of the residential area of which runs by unprofessional Labourers in (Baghdad July 2012 taken by author)*



*Figure2. Electricity connection cables have been added randomly without safety and security (Baghdad, July 2012 taken by author)*

A typical house located in a popular area in Baghdad was selected to serve as a base case for this research. The selected house was two stories high with a land plot area of 780 m<sup>2</sup>. Table 1 includes the highlights of the selected house. The house was modeled using ModelIT which is the model building component of the IntegrationEnvironment Solutions - Virtual Environment (IES-VE) modeling software. The ModelIt allows the user to create 3D models required by other components and enable appropriate levels of complexity to be incorporated within a model across the entire design.

*Table.1 Case study descriptions (typical house in Iraq/Baghdad)*

Item	Ground floor	1 <sup>st</sup> floor
Floor area (m <sup>2</sup> )	259.7	166.8
Total enclosed volume (m <sup>3</sup> )	779.2	500.5
Outside wall area (m <sup>2</sup> )	240.6	178.1
Glazing area (m <sup>2</sup> )	35	16.1
Window/wall ratio (%)	14.5%	8.9%

The IES – VE software offers the ability of creating different type of profiles for the same project. It is usually used to scheduled occupancy, HVAC system, and lighting, equipment, used according to the variation over a year. The operation profile of this study is based on the typical lifestyle of an Iraqi family. Three types of profiles have been setup which are; daily profile, weekly profile, and annual profile to provide accurate input data to obtained results with high level of validity. The daily profile assumes that from 8 am to 2 pm people will be out for work and education. Consciously the occupancy and the used of HVAC will be zero while it will be 1 unit when people will be back. (1 means 100% used in the software consideration) As well as the use of HVAC is linked to the occupancy profile. Meanwhile, weekend days have been assumed as full day occupancy and used (Iraqi families usually spend the weekend mainly at home). Thus it assumes the occupancy profile and HVAC system will be on continuously during the weekend days (Friday and Saturday). The annually profile is a frequently repetition of the weekly profiles, as exceptions it has adopted two types of profiles, for summer and winter. All these profiles have been considered for each simulation to increasing the reliability of the results. The IES-VE software provides the ability of creating different layers of constructions and finish materials according to the scenario of the simulation.

### 3. SIMULATION RESULTS

#### 3.1 Coefficient of Performance (COP) of Air Conditioning System

This scenario addresses the impact of chiller efficiency on total energy demand reduction through using another type of air-conditioning system. Many countries still neglect the significant importance of this strategy in order to achieve energy savings very easily within a limited time. According to the ASHRAE/IES Standard 90.1 [7] the efficiency of air conditioning systems have improved over the years in order to reduce energy consumption. The Coefficient of Performance (COP) of split units has improved from 1.7 in (1977-1997) to be 3.8 in 2006. This scenario increased the COP from 2.5 to 3.5 to examine the impact of the

air conditioning efficiency on energy demand reduction and savings. The results of this simulations show that the total energy was reduced from 139.6 MWh to be 127.8 MWh representing approximately 8.5% in reductions.

### 3.2 Solar Domestic Water Hot (SDWH)

According to solarelectricityhandbook.com [8] the most suitable angle of the sun in Baghdad, especially in coldest month such as January, is 41 percent from vertical. In order to face south, the simulation adopting azimuth angle is 180 clockwise from the north and the solar collector tilted toward 49 per cent from the horizontal as offered through IES-VE simulations. While the area varied as (2, 4, 6, 8 and 10) meters square to select the optimized case that reduced the boiler energy and did not affect the photovoltaic panel production. Regarding the previous results of the annual total energy consumption, boiler energy has the smallest part of the consumption, which means that the results of this scenario will not affect the total energy consumption as expected. The major impact will appear on the boiler load. The results show that the boiler load was been reduced from 0.1163 MWh to be 0.016 MWh. By selecting an area of 4 meter square, this gives enough space for the PV to be installed. Meanwhile, the balance between both strategies will achieve a significant increase in energy production while having a demand reduction. These simulations have been done separately to investigate the proper configuration for each one.

### 3.3 SunCast analysis

SunCast simulations show the upper roof received about (1845 kWh/m<sup>2</sup>) of solar radiation yearly. Part of the downstairs roof received the same amount with the exception of the shaded area that gained between (1521 - 1359 kWh/m<sup>2</sup>), this analysis aims to determine the best location of the PV, the roof specifications, shading profile, and the available area to achieve the highest level of efficiency. This simulation gives evidence that it is important to add the pergola to provide a suitable place for installing the PV and to avoid any shading factors that could reduce the output power of the PV system. The pergola was a part of the passive strategies as mentioned in the introduction, and it also offered shaded area services for the house.

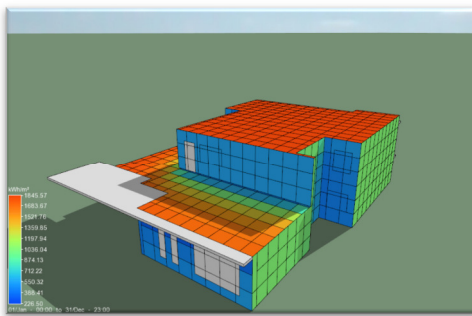


Figure 3 SunCast analysis

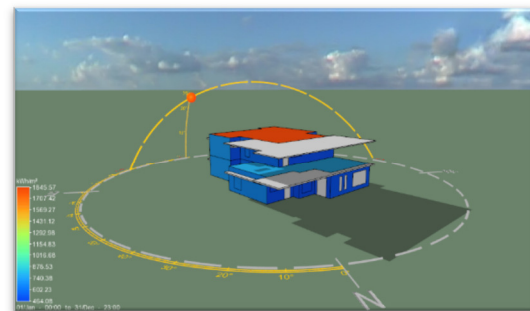


Figure 4 Adding Pergola to install PV

### 3.4 Optimized Angle of PV Panels

The first simulation of this scenario will adopt 166.8 m<sup>2</sup> area (second roof only) to be occupied by PV ignoring the first floor roof. This scenario assumed that the first floor roof will be used to apply the outdoor air conditioning system. Solarelectricityhandbook.com [8] provides the optimized monthly tilt angle in Baghdad, Iraq, throughout the year in order to achieve the greatest performance from the system. Five different angles have been selected to examine the most efficient one that could enhance PV production. The selection has been done according to peak radiation and the hottest months: June, July, and August. The other angles selected were in January and March. The angle for January was 49 degrees from the horizontal (90-41) while the azimuth was 180. In order to maximize the opportunity of facing south, consideration is given to the existing orientation of the case study. The simulations of each angle have been highlighted in Table 2 to understand the proper angle for energy production, angle 25° from the horizontal (equal to 65°) was considered suitable for August. The total annual production of PV increased through the changing of the tilt angles from 28.79 MWh to 30.76 MWh.

Table 2. PV production power of different tilted angles

	Case a	Case b	Case c	Case d	Case e
Angles from horizontal	49	33	10	17	25
Month	January	March	June	July	August
Total annual PV productions (MWh)	28.7959	30.5884	29.8057	30.468	30.7698

### 3.5 Optimized Area of PV Panels

This scenario examines the extended roof as pergola with the shading devices over the windows. The area of the roof, including the extension, is 300 m<sup>2</sup>. The total roof area will be 270 m<sup>2</sup> to install the PV panels because 10% has been reduced for maintenance. The simulation examines the Monocrystalline Silicon type of PV. The other type of PV cells will be tested in the next section. The results of the simulations show that the PV production was increased from 30.76 MWh 50 MWh representing 66.6%. Furthermore, the net energy demand was reduced from 127.8 MWh to 77.8 MWh giving a percentage reduction of 39.1%.

### 3.6 Photovoltaic Panels Performance

This scenario will examine the major differences in the types of solar cells between Monocrystalline Silicon, Polycrystalline, Amorphous Silicon, and Thin Film. According to Stapleton and Neill [9] the most efficient type is the Monocrystalline because it offers considerable performance when compared with other types of technologies. The utilization of these types varies from one project to another according to the available space, requirements, and preliminary cost. Monocrystalline silicon has been adopted for all previous simulations through IES-VE configurations. Due to the results of this scenario, the most efficient type of PV cells is Monocrystalline if one does not take into consideration the set up costs. Monocrystalline Silicon has the highest production which is 52.64 MWh, Polycrystalline Silicon production is 44.54 MWh, while Thin Film achieve 29.65, MWh and Amorphous Silicon has the minimum productin which is 21.91 MWh.

## 4. PV Production and Peak Demand

The occupied daily profile, assumes that people will be out from 8 am until 2 pm. Therefore, the use of energy drops to zero during this time period. On the other hand, the production of PV will peak during the daytime. The selected day is Wednesday, 18 August, which represents a normal workday during the hottest month as shown in figure 5. The graph indicates the gap between the energy producing times and the net electricity demand during the day. In addition, the actual demand has been dropped to zero from 8 am to 2 pm according to the occupancy profile. Meanwhile, the net energy demands are shown as a negative value because the amount of energy production is more than the energy consumption. Figure 6 shows the weekend of Saturday, 14 August. Overall, the energy produced should be stored until the demand time. Two solutions for this problema which are:

- 1- Stand-alone systems
- 2- Grid connected systems feed the electricity generated by the PV back to the grid, instead of storing it in a battery

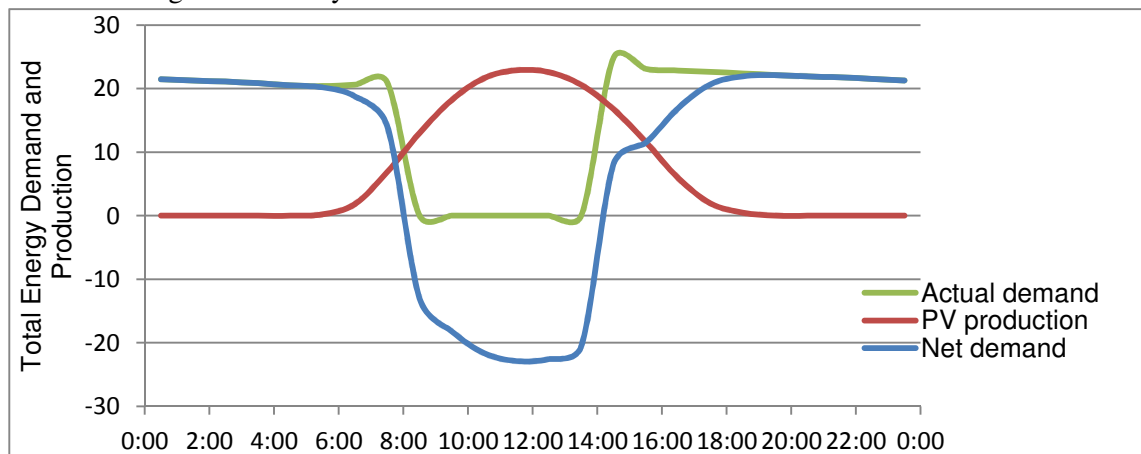


Figure 5. Peak time of PV production and net energy demand due to occupancy (22 of August, week day)

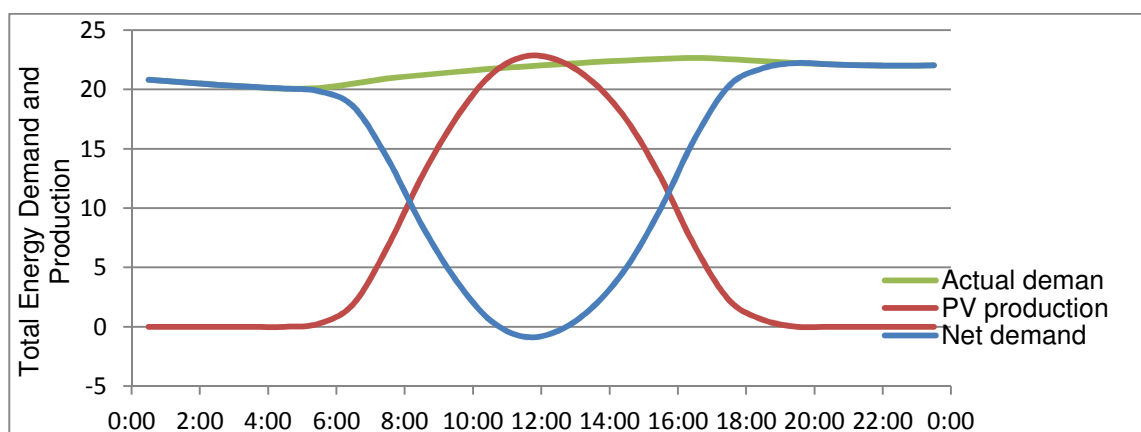


Figure 6. Peak time of PV production and the net energy demand due to occupancy (14 August, weekend)

## 5. CONCLUSIONS

The results show that the most effective active strategy and can be achieved quickly and easily by choosing an air conditioning system with more Coefficient of Performance (COP) This allows immediate energy reduction if cost issues are compared with energy savings. The research found that adding Solar DHW is not worth comparing with a lack of PV energy



production especially in hot climates. It was found that increasing the installing area of PV increases the PV production from 62.6% to 66.6%. In addition, the additional PV panels on window shading devices achieved 6.3% extra production. PV Panels performance depends on many factors, such as the availability of space, location being to the south, and shading profile. Thus, whenever the installing area for the PV increases, the energy production will be enhanced accordingly. Different types of PV cells were tested in the study to examine the level of performance for each model. The Monocrystalline is the most efficient type of PV cell, which provided the highest rate of energy production at 52.6 MWh. Although the initial cost of Monocrystalline is high, it is justified when compared to the output power. Polycrystalline has a lower price but lower efficiency. Finally, the production time of the PV needs to correspond with the demand time in order to avoid losing energy. The energy should be stored until the demand time, either through using a stand-alone system that utilizes a battery to PV system, or by using a grid-connected system, which feeds the electricity generated back to the grid. Overall, Increasing the Coefficient of Performance of the air-conditioning system could achieve an 8.5% energy reduction. , the net energy demand was reduced from 127.8 MWh to 77.8 MWh giving a percentage reduction of 39.1%. The integration of both the passive and active strategies can achieve a 50.6% energy demand reduction. Ultimately, the impact of each strategy will contribute to enhancing energy performance and savings. The study concluded that the integration of passive and active strategies significantly reduces electricity demand.

## REFERENCES

- [1] Ochoa, C. & Capeluto, I. (2008) Strategic decision-making for intelligent buildings: Comparative impact of passive design strategies and active features in a hot *climate Building and Environment* 43 (2008) 1829–1839
- [2] Silva, R., Arakaki, J., Junqueira, F., Filho, J., Miyagi, P (2012) Modeling of active holonic control systems for intelligent buildings *Automation in Construction* 25 (2012) 20–33
- [3] Alnaser, W & Al naser. N (2011) The status of renewable energy in the GCC countries *Renewable and Sustainable Energy Reviews* 15 (2011) 3074– 3098
- [4] Al – Badria, N & Abu-Hijleh. B (2013) Grid Electricity Demand Reduction through Applying Passive Strategies for a House in Baghdad - Iraq *SB13 Dubai Paper - 060*
- [5] Inter-Agency information and analysis (IAU). (July 2010) *Electricity in Iraq Factsheet*
- [6] U.N (2009) Meeting Coverage [online]. United Nations, Department of Public Information, News and Media Division, New York
- [7] Coupland, J. (1997) passive Solar-Heated Courthouse, and thermal performance *ASHRAE Journal*; Journal Volume: 39; Journal Issue: 12
- [8] Solar and Wind Energy *Solar electricity – the supporting pillar in the future energy mix* (2013) [online] Available from: <http://www.eng.dnt-solar.com/environment.html>
- [9] Staplton, G and Nilae, S (2012) *Grid-connected Solar Electric System The Earthscan Expert Handbook for Planning, Design and Installation*

## **The SUPER HABITAT project**

Style, O<sup>1</sup>; Soto, J<sup>1</sup>

<sup>1</sup> Asociación Slow Energy España, Segovia, Spain

*The Slow Energy España Association was formed in 2012 to promote energy culture in society through the identification, filtration, shaping and dissemination of useful concepts related to better living using less energy.*

*Its principal objective is to generate a social demand for solutions that improve our quality of life through improved indoor living conditions, presenting, in an attractive and simple way (1) the basic concepts and techniques for improving health and comfort in our homes, and (2) their practical application using a minimal amount of energy. The efficient diffusion of these concepts is intended to stimulate their adoption, not for reasons of energy efficiency, but rather because their application results in an improved quality of living.*

*The SUPER HABITAT project is one of the linchpins of Slow Energy's activities, consisting of the third edition of the widely distributed and previously named "Manual to stop you wasting energy".*

### ***Education, culture, living conditions, energy***

#### **Context**

Spain in the current decade presents a society immersed in uncertainty, plagued by profound economic problems and unprecedented levels of unemployment, together with the problems derived from chronic foreign energy dependency.

In this context the Spanish government needs to take complex decisions, further challenged by Spain's commitment to comply with emissions reductions in 2020.

The current scarcity of public funds and the excessive cautiousness of the private sector, driven by austerity policies, do not favour the short term success of public initiatives in the building energy efficiency sector. Social interest in energy saving is directly linked to economic benefits rather than environmental or sustainability criteria. It is, in any case, not a priority.

Let us take the example of the recent requirement for the energy efficiency certification of existing buildings. The measure is perceived as an imposition, and its educational value as a tool to raise awareness and generate data does not, as yet, work. Clearly, the process requires further development and consolidation. The usual key elements are missing: communication, education...the Administration must rethink its approach and understand that citizens need to be heard. Mainstream politics must be accompanied by social skills and communication. Currently citizens feel abandoned to their fate and any imposition incites rejection, especially when not adequately presented.



### **The SLOW ENERGY ESPAÑA Association**

ASEE was founded in Spain in 2012 by a handful of professionals specialised in energy efficiency and Passivhaus, born from the realization that a gulf exists between the energy culture of Spaniards and the basic knowledge an informed civil society should have in relation to energy solutions.

The benefits of sustainable construction certifications such as Passivhaus, BREEAM, Verde, Minergie etc., alongside a large number of disciplines related to energy and the environment, are debated by an enlightened public, generally professionals. However, the message does not reach people on the street.

It is in this context that ASEE seeks to close the loop, identifying and filtering pre-concepts that awaken interest in a non-technical public, shaping them into messages that are simple to understand, disseminated through efficient channels of communication that offer an effective diffusion and implantation of these messages.

To use IT argot, ASEE initiatives are analogous to open source plug-ins that allow for a more effective implementation of existing standards and techniques. They attempt to provide a human dimension to a technical message, breaking down barriers and facilitating understanding for people lacking in technical knowledge: people who will, in the future, be those demanding energy solutions.

From the ASEE prism, raising awareness (education, literacy...) in civil society is, without doubt, the principle challenge for the consolidation of energy efficiency measures, for two reasons:

- A citizen will never ask for a solution that he or she is unaware of, does not understand or does not want.
- The mass implementation of small-scale energy efficiency measures represents the only real way of reducing the national energy dependency.

Given the panorama presented above, what is the solution? The answer is to identify the techniques and habits that lead to energy savings and convince citizens to put them into practice. How can this be achieved? There are only two paths: imposition (regulations, standards, energy price rises...) and education.

In ASEE we think that technical professionals together with the Administration continue to make the same basic mistake. There is no point talking to the neighbour who lives on the third floor about energy efficiency. We must talk about health, accessibility, environmental quality and comfort...we must focus on what is truly important to people and then find solutions to resolve this, using the least possible amount of energy.

Mrs. Maria is bored of being told she must do an energy retrofit when she has serious problems paying the bills. Energy is perceived as boring, as well as a necessary resource on

which we are dependent and to which we are enslaved. Despite this, there are more pressing problems than energy.

Mrs. Maria should not be told she has to do an energy retrofit. Ideally, she will decide herself that this is what she should do. When this occurs, it's very probable that energy savings will not be her principle objective, but will have more to do with her well-being and that of her family.

ASEE is committed to education in the energy field. Together with numerous other organisations, ASEE exists to meet a need which, despite being the responsibility of the Administration, is being largely neglected, namely: literacy in energy saving.

### Manual to stop wasting energy

The SLOW ENERGY ESPAÑA Association has edited, in two consecutive years (2012 and 2013), two versions of a free publication that has been disseminated on a large scale, called "Manual to stop wasting energy". The manual brings together basic concepts in the field of bio-habitability, ergonomics (comfort), sustainable construction, passive building design, efficient heating and cooling systems, etc... transforming them into messages that are easily understood.

The key concepts proposed by our members have been stripped of technical content, making them accessible to a general public with no technical expertise, so that they can be easily understood, above all by school children.

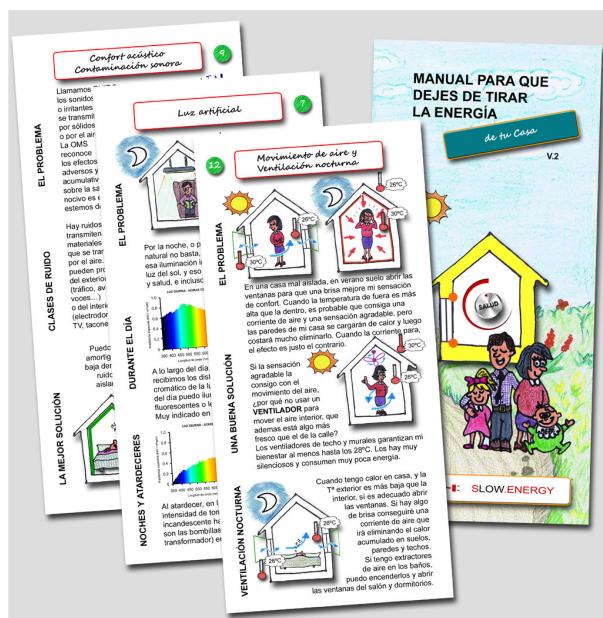


Image 1: Manual to stop wasting energy v.2

Embedded in this initiative is the understanding that the design of the message (purging of technical content, fresh ideas, highly visual, striking...) is as important as the effectiveness of its dissemination (penetration of the message, format, and intensity).



Contrary to the majority of campaigns, the here message is holistic (i.e. what really works is the combination of measures, rather than individual measures) and is addressed to both the layperson and the professional. The objective is to stimulate an informed demand for solutions that are currently not demanded, be it due to ignorance of their existence or a lack of awareness of their benefits.

The Manual is intended to be a self-teaching tool that opens the door to useful information, so that those who are interested can begin applying them and dig deeper in specific aspects that have caught their attention. There is a final message, namely that the extremes converge on common ground: improved hygiene and energy efficiency.

### **Dissemination**

Efficient dissemination of adapted ideas is as important as the identification and shaping of the concepts themselves. The distribution of the manuals is done exclusively by members of ASEE, either based on internal criteria or in response to external requests.

So as to maintain the impartiality and independence of the initiative and its contents, no commercial use of the Manuals is permitted. Their use is limited to educational activities only and they will always be FREE.

In regards to external requests for printed copies, priority is always given to the distribution of manuals in a context where their contents are presented by an educator or facilitator. Either way, best practice agreements are reached regarding their use and distribution, between ASEE, individuals and organisations (including private enterprises) who request copies.

- Members of the Association SLOW ENERGY ESPAÑA
- School teachers from primary onwards (over 6 years old up to pre-University) who see the Manual as an educational tool for their students. Complementary activities are also being developed involving parents.
- Environmental or social workers and consumer groups, who want to include the Manual as a new educational aid in talks and workshops.
- Training courses and Masters relating the fields of energy, comfort, bio-habitability, architecture and sustainable construction and/or low energy buildings.
- Congresses and Workshops related to the same areas.
- Members of organisations that share the message of the Manual
- Professional Colleges, Energy Agencies...

Below are some of the events in which the Manual has been distributed:

- Solar Decathlon Europe / Madrid, September 2012





- I & II Congress on strategies for the Energy Retrofitting of Buildings “ERE2+”/Madrid, 11-12 June 2013 and 6-7 May 2014
- II Congress of Architecture and Health / Barcelona, 20-21 June 2013
- 4th European Conference on Energy Efficiency and Sustainability in Architecture and Planning “EESAP4” / Donostia – San Sebastián, 1-3 July 2013
- 4th European Conference on Energy Efficiency and Sustainability in Architecture and Planning “EESAP4” / Donostia – San Sebastián, 1-3 July 2013
- Workshop on Energy Efficiency and Historic Buildings / Madrid, 25-26 September 2013
- I Technical Workshop on Architecture based on Sustainability, Energy Efficiency and Bio-Habitability / FENERCOM, SEEB Madrid 2014

To date 20,000 copies of the Manual have been distributed in a targeted manner, together with a further 20,000 downloads via the Association’s website, generating debate, articles and features in various media channels.

### **Education**

We live in a country where consumerism rules. Educating our children in conscious consumerism, not only in relation to energy, is vital. If we want our children to be free and responsible they need to know how to dispense with everything that is superfluous.

It therefore becomes particularly important to reinforce values of efficiency rather than wastefulness in our children’s education: this should be our principal objective.

The most recent studies show that the greatest part of our children’s education takes place at home, not at school. It is widely known that well-educated children generally come from educated families, irrespective of their place of learning...so teaching is done principally by parents rather than at school (with the exception of the motivated school teacher). But how are we going to educate our children in efficiency if we, their parents, don’t live by example or are not aware of what we should do?

The transformation of the current educational model towards new forms of generating knowledge would seem inevitable, one in which the transformational information is not simply found in a teacher’s head or in books, but rather extracted primarily from the internet and in audio-visual format. In this context, the qualification of parents and teachers in relation of information loses relevance.

Within this new educational paradigm, classrooms will be transformed into spaces where downloaded information will be experienced and contextualised. Parents and teachers who are truly concerned about a child’s education will work towards the transformation of information into knowledge...that is to say: they will teach them to think, not to memorise.



ASEE aims to participate in the development of balanced educational content in the field of sustainability and energy saving.

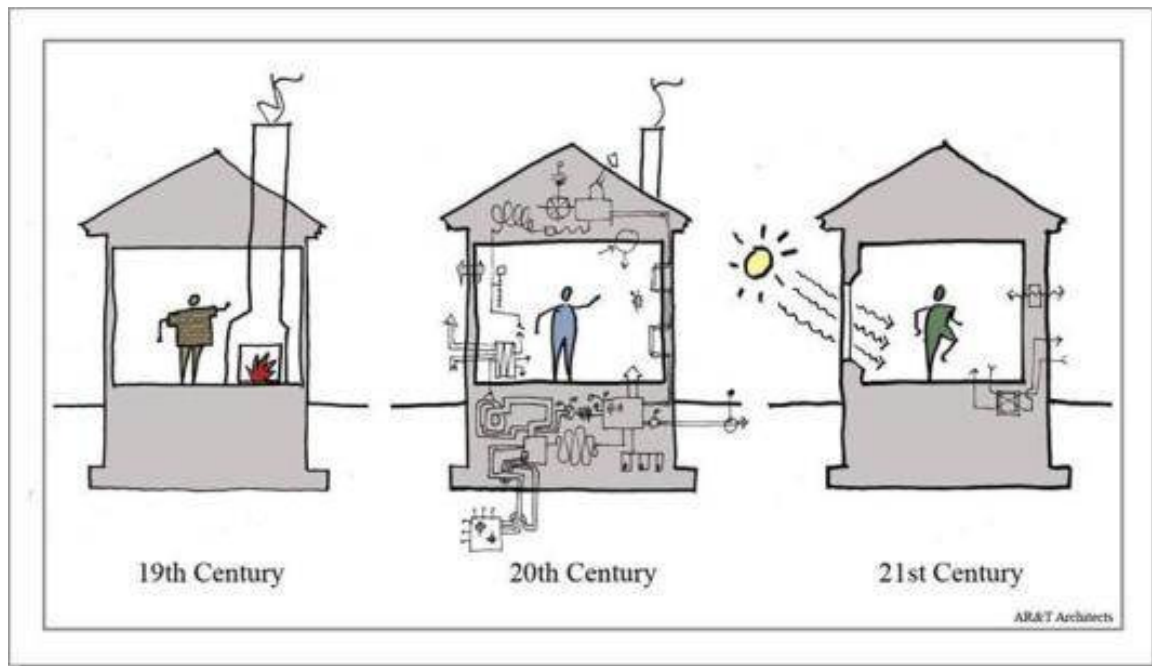
### **SUPER HABITAT**

In 2014 the 3<sup>rd</sup> version of the “Manual” is published, with new content and formats (printed and digital), and potential to reach new areas. Building on previous successes, ASEE hopes to create a headline reference publication on how to live (much) better using (much) less energy. Among those who have taken part in developing content are first grade technical professionals, social institutions related to the energy field and prominent game-changing individuals.

The 3<sup>rd</sup> edition reveals a significant development in the Manual and carries the title SUPER HABITAT. It brings together the following three distinct areas:

- Healthy indoor space (bio-habitability). This is the area of focus.
- Sustainable construction
- Nearly-zero energy buildings (passive and active strategies)

Achieving a SUPER HABITAT is done through the merging of the following disciplines:  
HEALTHY HOME + SUSTAINABLE HOME + PASSIVE HOUSE.



*Image 2: Evolution: we've moved from living in 19th Century houses (high levels of thermal inertia, lots of clothing and wood or coal burning stoves for comfort) to 20<sup>th</sup> Century homes (low levels of insulation with active systems for comfort) that allow for improved living conditions. If we want to take the new step towards 21<sup>st</sup> Century homes (optimum insulation, ventilation, and passive systems that provide comfort) we need to demonstrate to society that they provide far greater well-being (and, as if it was of minor relevance, use far less energy).*

Additionally, the educational objective of SUPER HABITAT is the presentation of solutions that notably improve our quality of life and that of our families. The methodology lies in ASEE's realisation that **what people really want is not to save energy or be more sustainable, but improved well-being.**

The goal is to provide a rodeo that offers society what it wants, beginning with the presentation of the potential improvements in our indoor habitat (bio-habitability) and subsequently proposing the most sustainable and low energy solutions that, in most cases, overlap. In this case, content is divided into various volumes. In 2014 these will be:

- Energy culture: Introductory volume presenting the problems facing society in general: scarcity of resources, climate change, fuel poverty, social inaction...
- Micro-monsters: Description of the toxins and contaminants present in the home, their name, how they arrive, what effects they cause and how to avoid them.
- Comfort: Places human value on the disciplines of ergonomics and our sensory input, providing the basis of low-cost solutions leading towards energy efficiency: air movement, radiant temperature, acoustic hygiene...The intelligent adjustment of these parameters makes achieving comfort possible with reduced energy consumption, even in inefficient buildings.



- Heat: A document explaining, in simple terms, what heat is and how it moves in and out of our home...
- Ventilation: A volume that is particularly important and a required discipline for the design of “nearly zero energy buildings” with high levels of air tightness, as a means of guaranteeing indoor hygiene, eliminating toxic contaminants and providing fresh air.
- Construction materials: Evaluation of materials in relation to their toxicity, environmental impact and energy use.
- Book of solutions: From low-cost solutions (do-it-yourself) to the most efficient solutions (Passivhaus). Priority is always given to solutions that significantly improve our health and /or indoor environment.
- The modular nature of content through the mass publication and distribution of printed volumes, covering a wide range of themes, will allow for new content to be generated on an on-going basis.

Over the course of 2014/15, ASEE’s objective is to disseminate selected SUPER HABITAT content to no less than 1,000 schools (primary and secondary), integrated into specific educational workshops.



IEA (2010). World Energy Outlook, IEA Publications

IEA (2012). Energy Technology Perspectives, IEA Publications

IEA (2014). Technology Roadmap. Energy storage, IEA Publications

Passer, A. et al. (2014). Sustainable buildings construction products & technologies. Proceedings of the International Sustainable Building Conference Graz 2013.

Schläpfer, M. et al. (2012). The Scaling of Human Interactions with City Size, CoRR .

Vianello, M. (2013). *Smart cities*. Maggioli.





## Typology of Representative Dwelling Designs for Technical and Policy Purposes in Australia

### Speaker:

Wong, James (P.C.)<sup>1</sup>

<sup>1</sup> RMIT University, Melbourne, Australia

**Abstract:** *Despite the importance of representative building designs for energy efficiency policy, to date there has been no serious attempt in Australia to develop a robust evidence-driven approach to this issue. This research project has developed a range of representative new dwelling designs through a hybrid approach of combining statistical and qualitative data sources. The recent residential building stock (2010-2012) in Australia was statistically analysed by reference to actual rating data records held by the Association of Building Sustainability Assessors. A survey of volume builders' typical building plans, together with spatial analysis of new construction regions across Australia, were combined with the statistical analysis to inform the production of representative concept floor plans and associated dwelling descriptions. A comprehensive new residential building typology is presented with clear categories of 'typical' dwelling structures grouped under various building types, number of storeys, number of bedrooms and the form of the building plans.*

**Keywords:** *Residential building, energy performance, building typology, energy efficiency policy*

### Introduction

Building-related greenhouse gas emission policy in Australia has directed attention to improving the energy efficiency of building fabric in new construction. Energy efficiency provisions for housing were introduced in the Building Code of Australia to achieve a nominal level of energy efficiency approaching a rating of 4 stars in 2003, 5 stars in 2006 and 6 stars in 2010, based on the Nationwide House Energy Rating Scheme [1].

The potential for further energy efficiency improvements and emissions reductions from the residential sector is well established [2]. Strategies for improving building energy efficiency are an important consideration of government policy, which includes setting goals and pathways to zero-energy or zero carbon buildings [3, 4, 5].

In 2005, the Australian residential sector accounted for approximately 13% of the country's total GHG emissions [6]. Improving energy efficiency in residential buildings would contribute significantly to GHG emission reductions by the building sector. Australia has currently committed to meeting a long term target of a 60% reduction of GHG emissions by 2050 based on 2000 levels, as well as to reduce GHG emissions by 5-15% below 2000 levels by 2020 [3].

Development of a sound methodology to analyse the energy performance of building stock by classifying existing buildings by typology and then modelling the energy use of 'representative' buildings is an effective way to inform policy and improve energy



performance in residential building stock was being proven in a number of similar overseas initiatives [7, 8]. The TABULA Project has developed residential building typologies for 13 European countries, with each national typology consisting of a classification scheme that groups buildings according to their size, age and associated parameters. A set of 'representative' buildings represents the different classes of building types [9]. These building typologies are used for energy performance assessment of national building stocks.

In Australia, research has been carried out to investigate the cost savings through residential building redesign to achieve required building energy standards using a range of common dwelling types sourced from major property construction companies [10]. Foliente et al. [11] has proposed a bottom-up modelling approach to systematically assess the energy use of the building stock was proposed and demonstrated in a case study of office buildings in the state of NSW. The specific building stock energy use was categorised by building type, end-use and spatial distribution.

## **Methodology**

A set of dwelling designs that represent the national new building stock is developed for technical and policy purposes, by analysing and surveying existing literature, building stock databases and relevant documentation. The set of dwelling designs represent commonly occurring, characteristics of a particular type of building, based on a statistical analysis of large existing databases for appropriate levels of grouping. Descriptions of these representative building designs are provided so that they can be modelled with the Nationwide House Energy Rating Scheme (NatHERS) software.

A review of building typologies in literature and reports was undertaken to guide the development of a typology for the representative dwelling designs. ABSA Certificate Manager Database, ABS and other relevant databases, including sales building data, state-based Valuer General Data, were assessed for their usefulness in establishing statistically valid samples of new residential building stock (between 2010 and 2012), for developing representative dwelling designs.

## **Research on Representative Dwelling Designs**

Data from the ABSA and ABS databases has been extensively analysed. Data on new residential building stock were categorised by various building types/dwelling structures (e.g. single storey detached), building sizes (e.g. dwelling less than 150 square metres), BCA climatic zones (e.g. zone 6-mild temperate), and selected design features that affect building energy and environmental performance (e.g. 600mm roof eave). These categorised data were subsequently cleansed for outliers to improve the quality of the data.

Typical floor plans and building forms for different types and sizes of dwelling were developed from common residential building designs supplied by major building developers in Australia. More than 60 dwelling designs were obtained from ten major residential developers and private residential owners. These common dwelling designs cover the various



States and Territory and some have been constructed from plans provided by the private owners.

Survey questions pertaining to the high-selling and typical examples of new homes (with the initial formulated typical floor plans) are sent to the selected major building developers for feedback and comments.

The formulated typical building plans for separate houses, attached houses and apartments are further refined through sensitivity analysis to determine the effect of selected design factors (e.g. eave width) on building energy performance.

Spatial analysis techniques are also used to study the correlation between the building typology descriptive information and building locations to identify the influence of climatic conditions toward building design features.

### **Development of Representative Dwelling Designs**

The building typology and common building floor plans were combined to produce a set of sixteen national 'representative' dwelling designs.

The specifications of the 'representative' dwellings can be modified to achieve the minimum star rating standard required in a particular State or Territory. When modelled in NatHERS, the representative dwellings have a star rating equal to, or slightly higher, than the minimum standard.

Design parameters investigated in the development of the set of representative dwellings includes conditioned and unconditioned floor area, external wall area, window area and orientation, eave width and offset, window size, window U-value and solar heat gain coefficient, roof colour and insulation, building materials R-value, and building layout.

### **ABS Data Analysis**

An analysis of ABS data indicates approximately 98% (8.4 million) of Australians live in private self-contained dwellings. Of these, 79% live in separate (detached) houses, 11% in flats, units or apartments, and 10% in semi-detached, row or terrace houses or townhouses. Typically, separate houses have 3 or 4 bedrooms; semi-detached houses have 2 or 3 bedrooms, and flats, units or apartments have 1 or 2 bedrooms. In 2009-10, 78% Australian households live in dwellings (mainly separate houses) with 3 or more bedrooms, 18% live in dwellings with 2 bedrooms and 4% live in 1 bedroom dwellings (mainly flats, units or apartments) [12].

Figure 1 shows the distribution of dwelling structure by number of bedrooms according to the ABS census data. The census data does not differentiate the number of storeys for separate houses. 'Building Stock %' in the table is tabulated as the percentage of the dwelling structure type within its own type for better understanding of the distribution of the building stock. The tabulation excludes 'other dwellings' and 'dwellings structure not stated' as formulated in the

ABS census data. The dwelling types shaded in 'blue' are considered the main types as they constituted more than 10% of their respective building stock. The dwelling types shaded in 'green' are considered sub-types as they represent 5-10% of their respective building stock.

Dwelling Structure (Dwelling Type)	No. of storeys	1 bedroom		2 bedrooms		3 bedrooms		4 bedrooms		4 bedrooms +	
		No.	% of Dwelling Type	No.	% of Dwelling Type	No.	% of Dwelling Type	No.	% of Dwelling Type	No.	% of Dwelling Type
Separate house	1+	65005	1.1%	568512	9.7%	2839940	48.4%	1850583	31.6%	393131	6.7%
Semi-detached, row or terrace house, townhouse	1	38818	5.1%	200991	26.2%	171532	22.4%	21927	2.9%	3674	0.5%
	2+	13181	1.7%	81990	10.7%	162549	21.2%	32411	4.2%	5836	0.8%
Flat, unit or apartment	1 to 3	148575	14.1%	446823	42.3%	118434	11.2%	8172	0.8%	2561	0.2%
	4+	64704	6.1%	149513	14.2%	46671	4.4%	2036	0.2%	571	0.1%

Figure 1 Dwelling structure by number of bedrooms distribution

### ABSA Certificate Manager Data and TCO Data Analysis

The ABSA databases comprise the Certificate Manager Data, with more than 268,000 datasets (i.e. projects) from 2005 to 2011, and The Certificate Office (TCO) Data, with more than 8,000 datasets from 2010 to 2012. As this research is only concerned with data from 2010 to 2012, both ABSA datasets were 'mapped' to exclude duplicate data. The final number of datasets analysed was 56,170.

The ABSA database contains approximately 225 building information parameters. Of these, 51 parameters were found to be relevant to this project, including climate zone, external wall construction, window area, star rating, roof covering and insulation.

The number of new dwellings constructed from 2010 to 2012 is approximately to 471,054 [13]. The sample size required for a confidence level of 99% with confidence interval of 1 (information is highly reliable) for the population of 471,054 dwellings is 16,073. The 56,170 datasets analysed in this project represents approximately 12% of the total new dwelling stock and also represents a good statistical sample number.

Figure 2 shows the most common roof eave width for detached dwelling in climatic zone 1 is 900mm and 600mm in climatic zones 2 and 3. Roof eave width of 450mm is the common length for the rest of the climatic zones as indicated.

Figure 3 shows conditioned floor areas for different types of dwellings. The range of conditioned floor are for apartment unit is 50-100m<sup>2</sup>, for single storey dwelling is 100-150m<sup>2</sup>, and for double storey dwelling is 100-250m<sup>2</sup>.

### Survey of Typical Residential Building Plans

Residential building plans from ten major house developers were examined to determine common building designs on the market for detached, semi-detached and apartment dwellings. The findings of this survey, together with the analysis of ABS building stock

statistics, provided the grouping method for the main building categories (e.g. separate/detached) into one-storey or two-storey building (with 3 or 4 bedrooms, etc).

The aerial photographs survey confirm that dwellings in hotter climates, like Darwin, typically have lighter roof colours, while in colder climates, like Melbourne, darker colours are typically used. Most dwellings are of rectangular shape but some are square shape. Some of the buildings seem to have been ‘mirrored’ compared to the adjacent surrounding buildings perhaps for better solar orientation optimisation.

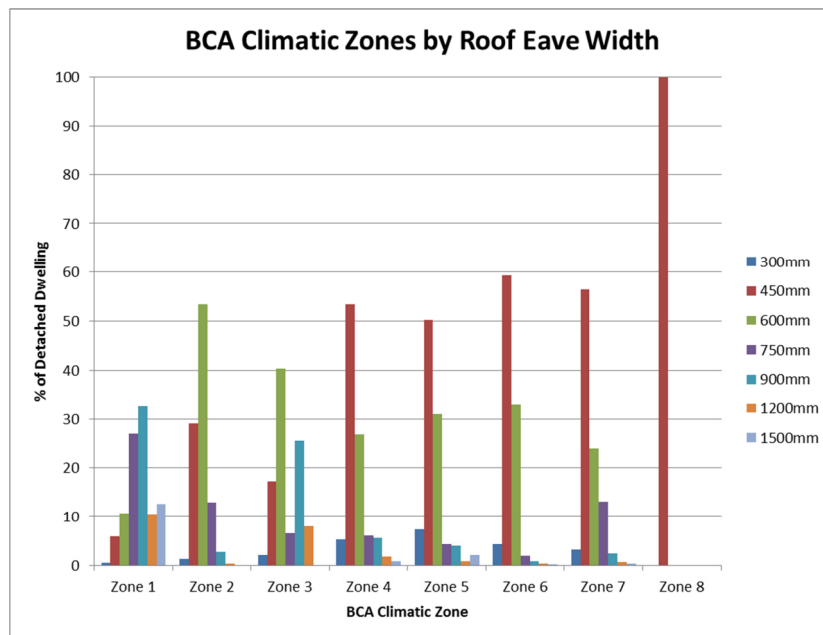


Figure 2 Roof eaves width distribution in BCA climatic zones

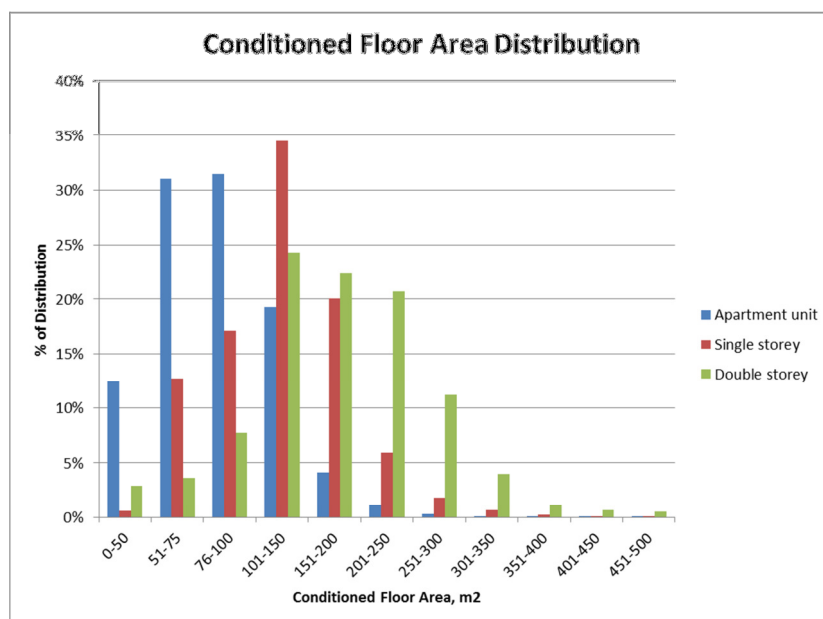


Figure 3 % of detached dwelling distribution with various roof eaves in BCA climatic zones



## Simulation Analysis of Typical Residential Building Plans

Typical building plans for separate houses, attached houses and apartments are created from an analysis of ABS data, ABSA data and developer building designs. A sensitivity analysis of the typical building plans is undertaken using the NatHERS software to determine the effect of selected design factors on building energy performance.

## New Residential Building Typology

This research shows that the most common new residential dwelling for separate (detached) houses is a 3-bedroom dwelling, for attached houses is a 1-storey 2-bedroom dwelling and for apartments is a walk-up 2-bedroom unit. The dwelling types shaded in 'blue' are considered the main types as they constituted more than 10% of their respective building stock. The dwelling types shaded in 'green' are considered sub-types as they represent 5-10% of their respective building stock. Therefore the main dwelling types for walk-up apartment are 1-bedroom, 2-bedroom and 3-bedroom dwellings, and consequently the sub-type for high-rise apartment is a 1-bedroom dwelling.

Figure 4 shows the proposed new residential building typology formulated through the analysis of the ABS data, ABSA data and survey of typical building plans from property developers. The 'representative' dwelling plans are combined with construction descriptions and essential dimensions to allow modelling in NATHERS software.

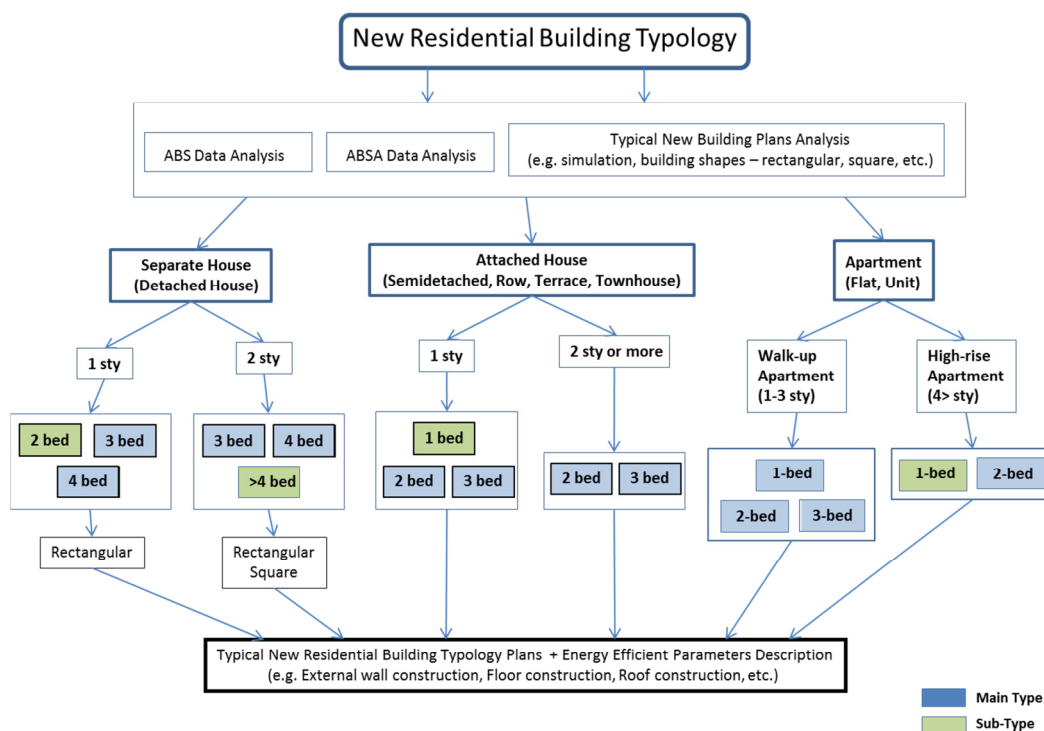


Figure 4 New residential building typology

## Conclusion



A comprehensive new residential building typology is presented with clear categories of ‘typical’ dwelling structures grouped under various building types, number of storeys, number of bedrooms and the form of the building plans. This new building typology together with the ‘typical’ building plans (with building construction descriptions) provide valuable resource for analysing the energy performance of the residential building stock and for future policy application to improve the overall energy performance of the Australia residential building stock.

## References

- [1] Australian Building Codes Board. (2010). *Energy Efficiency Provisions for Housing*, from <http://www.abcb.gov.au/index.cfm?objectid=7384D70B-28B9-11DE-835E001B2FB900AA> [Accessed: 26 March 2014].
- [2] Metz, B., Davidson, O., Bosch, P., Dave, R., et al. (Eds.). (2007). *Climate change 2007 - mitigation of climate change (contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change)*. New York, N.Y.: Cambridge University Press.
- [3] Australian Sustainable Built Environment Council. (2009). *Developing an Australian Net Zero Energy Homes Coalition - Background Paper*. Sydney: Australian Sustainable Built Environment Council (ASBEC).
- [4] European Commission. 2009. *Low Energy Buildings in Europe: Current State of Play, Definitions, and Best Practice*. Brussels: European Commission.
- [5] Task Group on Energy Efficiency. (2010). *Report of the Prime Minister's Task Group on Energy Efficiency*. Canberra: Department of Climate Change and Energy Efficiency (DCCEE).
- [6] The Centre for International Economics. (2007). *Capitalising on the building sector's potential to lessen the costs of a broad based GHG emissions cut* (Prepared for ASBEC Climate Change Task Group). Canberra: Centre for International Economics (CIE).
- [7] Theodoridou, I., Papadopoulos, A.M. and Hegger, M. (2011). A Typological Classification of the Greek Residential Building Stock. *Energy and Buildings*, 43, pp.2779-2787.
- [8] Korolija, I., Marjanovic-Halburd, L., Zhang, Y. and Hanby, V.I. (2013). UK Office Buildings Archetypal Model As Methodological Approach in Development of Regression Models for Predicting Building Energy Consumption from Heating and Cooling Demands. *Energy and Buildings*, 60, pp.152-162.
- [9] Loga, T. and Diefenbach, N. et al. (Eds.). (2010). *TABULA Project: Typology Approach for Building Stock Energy Assessment*. Institut Wohnen und Umwelt GmbH, Germany.
- [10] Sustainability House. (2012). *Identifying Cost Savings through Building Redesign for Achieving Residential Building Energy Efficiency Standards*. Department of Climate Change & Energy Efficiency, Canberra.
- [11] Foliente, G and Seo, S. (2012). Modelling Building Stock Energy Use and Carbon Emission Scenarios. *Smart and Sustainable Built Environment*, Vol. 1, No. 2, pp.118-138.
- [12] ABS (Australian Bureau of Statistics). (2012). *Year Book Australia*, Australian Bureau of Statistics, Canberra.
- [13] ABS (Australian Bureau of Statistics). 2013. *Building Approvals. Cat. no. 8731.0*, Australian Bureau of Statistics, Canberra.

*Modernization of Multi-Storey Apartment Houses*

**Speakers:**

Miniotaite, Ruta<sup>1</sup>; Ziogas, Vigantas, Antanas<sup>1</sup>; Medeliene, Violeta<sup>1</sup>; Juociunas, Svajunas<sup>1</sup>

<sup>1</sup> Kaunas University of Technology, Kaunas, Lithuania

**Abstract:** *The article presents a position of the author on the problems of the modernization of the multi-storey apartment modernisation process in Lithuania according juridical, social, ecological, technical-technological and economical aspects. When the decision to renovate the multi-storey apartment houses is made, first the juridical problems have to be solved. These problems involve planning of investment project, social problems of individual flat dwellers and the infringement of their rights. In many cases the modernization of multi-storey apartment houses is suspended because of the improper solution of juridical and social questions. Other modernization problems are: unqualified house energy audit making, technically unsound heating insulation and architecture of house facade decisions, and final approximation all decisions. Designing a technical project for the multi-apartment house modernization, it is necessary to make a precise evaluation of heat loss before and after the modernization, to calculate the modernization workload and the expected decrease of heat consumption.*

**Keyword:** *Multi-storey apartment houses, modernization, technical-technological solutions*

**Introduction**

Modernisation of multi-apartment houses is a topical issue, huge funds are allocated for its advertisement, but this didn't stimulated to perform rational planning, design, renovation and to solve ecological, economical and social problems. Recently according to the programme for modernisation of multi-apartment houses approved by the Government of the Republic of Lithuania, just 38 % of modernisation is implemented. This means, that it is necessary to look for causes of the failure, and the programme for modernisation of multi-apartment houses must be improved.

The research projects were performed, the programmes for renovation of multi-apartment houses were developed evaluating the following aspects: technical – technological, thermal resistance increase and heat consumption decrease, possibility of alternative sources. Recently many research works are performed about the evaluation of the multi-apartment house renovation efficiency [1, 2, 3]. The problems of thermal comfort and energy demand are analysed, applying radiant ceiling panel heating-cooling systems [4]. In other works it is proposed to renovate residential districts in complex and thus achieve the most effective results [5]. Practically there are insufficiently analytical works about the heat energy producers and suppliers' energy production costs, and the validity of profits.

Organizing the multi-apartment house renovation, in the initial phase it is necessary to solve legal problems correctly, considering the social aspects of home-owners, and to design renovation stages according to the interests of home-owners majority. The investment-



technical project is designed without calculation of heat loss before and after renovation, workload is incorrect according to the insulation solutions made for the renovated house.

The Housing and urban development agency coordinates the performed renovation (insulation) works according to the three work groups: insulation of external partitions, roof insulation and replacement of windows. The application of the performed large work acts enables the foremen to act unfairly.

The majority of Lithuanian multi-apartment houses are built according to the standards that do not ensure an effective use of heat energy. According to the data of the Programme for Renovation of Multi-apartment Houses, approved by the Government, 28 % of multi-apartment houses in Lithuania are built before 1940, 10 % during 1941–1960, 56,5 % during 1961–1992 year. Improper heat insulation of multi-apartment houses, old common use equipment for heat energy transmission increase the heat energy input, which determine the heating costs. In order to decrease the heating costs it is necessary to take legal and financial actions that ensure the efficient use of heat energy in multi-apartment houses [6]. The renovation of multi-apartment houses is one of the main actions ensuring the efficient use of heat energy. This action is not new in Lithuania, as in 2009 the legal basis for house renovation was developed and models of state support for renovation were foreseen.

The renovation of multi-apartment houses is regulated by: EU legal acts; Lithuanian Law; Legal regulations.

Promoting the renovation of the dwelling houses, the state provides support for preparing and implementing the modernisation projects. The State provides assistance to residents in the preparation of technical documentation for renovation projects, organising their implementation. Up to 100 % expenses needed for documentation preparation are reimbursed for residents, if the building energy efficiency level (not less than class D) is achieved according to the implemented measures.

At present the state will provide financial support that constitutes 15 % of the renovation project if the energy saving is 20 %. If the saving is not less than 40 %, then 30 % of the performed contract work will be reimbursed.

Lithuania Law that regulate the renovation of multi-apartment houses: The Civil Code of the Republic of Lithuania, Law on State Support to Acquire or Rent Housing and to Renovate (Modernise) Multi-Apartment Houses of the Republic of Lithuania, Law on Cash Social Assistance for Poor Residents of the Republic of Lithuania; Law on Home Owners' Associations of Multi-Apartment Buildings of the Republic of Lithuania, Law on Construction of the Republic of Lithuania, Law on Public Procurement of the Republic of Lithuania [7-10].

Seeking to speed up the renovation process of multi-apartment houses, the Government developed a financial model for the renovation (modernisation) of multi-apartment houses. There different financial sources for the renovation of multi-apartment houses are foreseen:



European Union's, State Budget's and residents' funds. Possibilities to use the EU funds for the renovation of multi-apartment houses are provided by the EU initiative JESSICA (*Joint European Support for Sustainable Investment in City Areas*). JESSICA initiative was developed by the European Investment Bank (EIB) together with European Commission in cooperation with the Council of Europe Development Bank [11]. Lithuania is one of the first states in European Union that applied JESSICA initiative to increase energy efficiency.

Making use of this initiative, Member States may allocate part of their EU structural funds for repayable investments in projects of sustainable cities. When the possibilities of the initiative application in Lithuania were analysed, first it was decided to invest into energy efficiency, so into the renovation (modernisation) of old multi-apartment houses.

According to the developed model the funds for the renovation of multi-apartment houses will be allocated from the Holding Fund. The Holding Fund was established by the Ministry of Finance and the Ministry of Environment of the Republic of Lithuania and EIB (the latter is appointed as a fund manager). The bank has prepared the competition conditions to select financial intermediary of the Holding Fund. The Fund controlled by EIB will provide long-term low-interest loans for residents who want to renovate their houses via the financial intermediary. The funds invested into the projects for renovation of multi-apartment houses will return to the fund and they will be re-invested. The project's payback is caused by the efficiency of implemented energy efficient measures (e.g. roof and wall insulation, renovation of heating system, replacement of windows with new ones, balcony glazing, etc.) and therefore the reduced fee for heating. The state will help the residents by reimbursing a part of modernisation works. From 1 January, 2014, 50 % of costs are reimbursed organizing the project implementation. The state will pay the loan repayment and interests for people who have a right to compensation for heating. From 1 January, 2014, 50 % of expenses are reimbursed.

All the necessary preparatory works related to the renovation of a dwelling house may be performed in three main stages: 1) a preliminary proposal for residents about the house modernisation expedience is prepared; 2) the owners decision is made; 3) the house modernisation project is designed.

A decision on a house modernisation is made at the general meeting of home-owners, organized by the manager of common use equipment in accordance with the community statutes or agreement of the apartment and other premises owners joint action, and if the joint action agreement is not available or absent, then according to the Civil Code.

The problem of multi-apartment houses modernization has to be analysed in complex, evaluating legal, social, technical-technological, economic and ecological aspects.



### Technical-Technological Solutions for Renovating a Multi-Apartment Ceramic Brick House

When the renovation is performed to the multi-apartment house of complicated configuration, with protruding attached piers and parts of building, then several solutions for wall insulation must be made. When multi-apartment ceramic brick house with attached piers and parts of building are renovated, 3-6 solutions for external wall insulation can be made, and 1-3 solutions can be made for socle. This type of house is insulated with expanded polystyrene of 150, 100 and 50 mm, the wall of the first floor – with stone wool of 130, 80 mm, socle with stone wool of 80 mm and expanded polystyrene of 100 mm (Figure 1).

The finishing is made of two layers: the main layer which is reinforced with mesh and the structural decorative plaster. The total width of both layers is 3 mm. Decorative fiber cement panels („Minerit“ 8 and 12 mm) were used for the first floor and the socle.

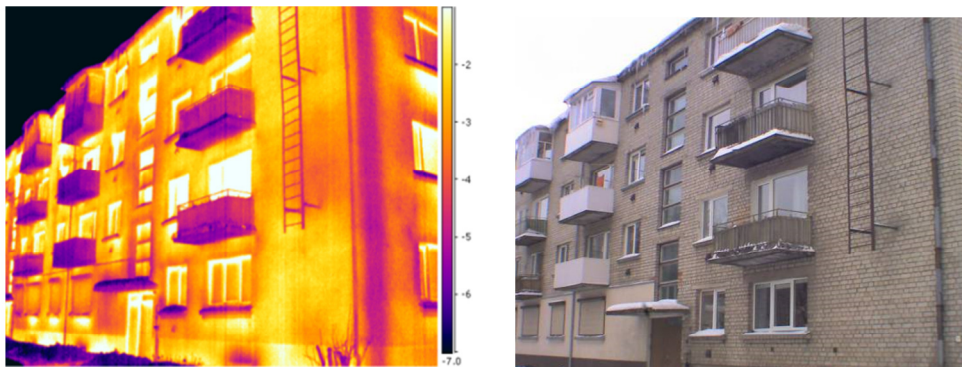


Figure 1. Fragment of wall renovation

Renovating this type of a house, it is necessary to evaluate, whether it is expedient to insulate the protruding attached piers. The insulation of protruding attached piers increases the insulation area up to 35 %, as well as the renovation expenses. The primary calculations were performed [12] and tentatively it was stated that when external walls are insulated qualitatively and when protruding attached piers of landing are not insulated, the heat losses are insignificant, and there is no danger for dew point formation. In the future this question must be researched elaborate. When the roof is renovated, the following solution is made: 150 mm expanded polystyrene + 40 mm stone wool insulating layer and 2 layers of hydro-insulating coating.

Evaluating the work quality of external wall insulating, it is found that facing with stone wool is often performed not qualitatively, gaps between stone wool pieces are left, a windproof, diffusion-permeable membrane is not applied. The insulation under the iron window sills is performed not thoroughly (just spot gluing with foam). Evaluating the work quality of structural layer application, it was found that the structural layer at the beginning of renovation was just 0.9-1.2 mm thick, when according to the standards it must be 3 mm. The foremen had to perform qualitative work and increase the structural layer thickness up to 3 mm after the repeated inspections and constant control. The scientific sources show that when the structural layer is not optimal, a few years later it starts cracking and humidity penetrates



into insulating material, therefore its thermal insulation properties become worse. So, in this investigation case the decrease of heat consumption for  $1 \text{ m}^2$  after the renovation depends on the fact whether the external wall insulation was performed qualitatively.

## Conclusions

Designing a technical project for the multi-apartment house renovation, it is necessary to make a precise evaluation of heat loss before and after the renovation, to calculate the renovation workload and the expected decrease of heat consumption.

Performing the renovation works constant and qualified supervision must be performed. The improperly attached and unsealed insulation material must be repaired, and decorative structural plaster must be of the designed thickness.

The renovation of multi-apartment houses that are built of ceramic perforated bricks and cellular concrete base will payback in 25 years. Actually home-owners do not have any economic benefit because of the rising heat selling prices. But after the renovation the living conditions are improved, heat energy is saved state-wide, and environmental pollution is reduced.

In the future the renovation expenses for home-owners must be calculated according to insulated area.

In the future the analysis and supervision of heat producers' and suppliers' large profits validity must be performed, as the performed renovation must be beneficiary for home-owners too, the payback period should decrease and the renovation become less stagnant.

## References

- [1] Biekša, D., Siupsinskas, G., Martinaitis, V., Jaraminiene, E. (2011). Energy efficiency challenges in multi-apartment building renovation in Lithuania. *Journal of Civil Engineering and Management*, 17(4): 467-475.
- [2] Rapceviciene, D. (2010). Evaluation of multi residential house renovation efficiency. *Science – Future of Lithuania*, 2(2): 83-89.
- [3] Martinaitis, V., Kazakevicius, E. (2007). A two factor method for appraising building renovation and energy efficiency improvement projects. *Energy Policy*: 192-201.
- [4] Miriel, J., Serres, L., Trombe, A. (2002). Radiant ceiling panel heating-cooling systems: experimental and simulated study of the performances, thermal comfort and energy consumptions. *Applied Thermal Engineering*, 22: 1861-1876.
- [5] Zavadskas, E.K., Raslanas, S., Kaklauskas, A. (2008). The selection of effective retrofit scenarios for panel houses in urban neighborhoods based on expected energy savings and increase in market value. The Vilnius case, *Energy and Buildings*, 40(4): 573-587.
- [6] Renew dwelling. *Legal basis*, <http://www.atnaujinkbusta.lt>.



- [7] Legal news. GLIMSTEDT, 2012 05 (1). [http://www.lsta.lt/files/seminarai/2012-05-22\\_Glimstedt/6\\_GLIMSTEDT%20Teises%20zinios%202012-05.pdf](http://www.lsta.lt/files/seminarai/2012-05-22_Glimstedt/6_GLIMSTEDT%20Teises%20zinios%202012-05.pdf).
- [8] STR 2.05.01:2005. [http://www3.lrs.lt/pls/inter2/dokpaieska.showdoc\\_l?p\\_id=260821](http://www3.lrs.lt/pls/inter2/dokpaieska.showdoc_l?p_id=260821).
- [9] STR 2.01.09.:2005. [http://www3.lrs.lt/pls/inter3/dokpaieska.showdoc\\_l?p\\_id=268553](http://www3.lrs.lt/pls/inter3/dokpaieska.showdoc_l?p_id=268553).
- [10] STR 2.09.04.:2008. [http://www3.lrs.lt/pls/inter3/dokpaieska.showdoc\\_l?p\\_id=320473&p\\_query=&p\\_tr2=](http://www3.lrs.lt/pls/inter3/dokpaieska.showdoc_l?p_id=320473&p_query=&p_tr2=)
- [11] JESSICA. web access: [http://www.eib.org/products/technical\\_assistance/jessica/](http://www.eib.org/products/technical_assistance/jessica/).
- [12] Ruseckas, J. (2009). Methodical principles of complex multistorey apartment buildings reconstruction. *Science – Future of Lithuania*, 1(5): 72-78.

## Thermal Environment in Main Room Models of Contemporary Houses in Hokkaido, Japan

### Speakers:

Fujiwara, Kisa<sup>1</sup>; Murata, Ryo<sup>2</sup>; Yuasa, Kazuhiro<sup>3</sup>; Yasuda, Koichi<sup>4</sup>

<sup>1</sup> PhD student, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Tokyo, Japan

<sup>2</sup> Associate Professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Tokyo, Japan

<sup>3</sup> Associate Professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Tokyo, Japan

<sup>4</sup> Professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Tokyo, Japan

**Abstract:** *This study aims to clarify how the room form and other factors have effects on indoor thermal environment and find out the thermal environment characteristics of models of main rooms such as a living room, in contemporary houses in Hokkaido, a cold climate area in Japan. We extracted eight basic form prototypes of modern houses in Hokkaido by their spatial dimension and the way of responding to the outside. In addition, we analyzed alternates that were changed from prototypes respectively and combinatorially in terms of building performance and living style. A PASSWORK design tool was used in this study to calculate the air conditioning load of each model. The present study has demonstrated the thermal environment characteristics of main room models of contemporary houses in Hokkaido and suggested the possibility to make an intimate relationship between indoor and outdoor spaces by using large windows in houses in cold climate areas.*

### ***Cold Climate Housing, Form, Heat Load, Indoor Thermal Environment, Parametric Study***

#### **1. Introduction**

The realization of comfortable house environment corresponding to the outdoor environment is a universal theme in designing houses and there is a lot of originality to achieve thermal comfort in each region.

This study focuses on how houses should be designed to adapt themselves to Hokkaido, the northern part of Japan and the winter temperature goes down to subzero. In designing houses in Hokkaido, measures against the cold weather are significant. Therefore, the principal objective for the development of the building technology in this region is “how to spend in winter comfortably” and an adiabatic construction method and heating technique have been studied and



**Image1. Houses in Hokkaido**

1-1 photo by Yoshiyuki Tsukada of Asahi Shinbun  
1-2 photo by Ping Hui

developed. The indoor environment comfort in winter greatly improved with these developments. After the establishment of “Act on Promotion of Construction, etc. of Housings with Cold Weather Protection in Hokkaido” in 1953, Hokkaido Housing Public Corporation played a key role and supplied concrete block construction houses as fireproof houses with protection against the cold. These houses with characteristics such as “Center-living room” and “Small windows” were typical in several decades. Various trials and errors to “open windows to solid walls” have been performed to adopt light and scenery without conveying cold from outside to inside. Recently, the housing has come to be designed more open: it has large windows to enable it to take light and have scenery aiming to suit its climate through the year as well as winter. Such changes in designing houses indicate that the various balances of space and environment has been considered in response to this local climate.

In addition, various room compositions are derived from “Center-living room” and many examples of contemporary houses whose plan is based on the living room were observed: a dining room and a living room adjoin, and a bedroom and a living room adjoin the upper part of the colonnade of a living room. Therefore, focusing on such continuous space connected with a living room would clarify how designers balance space and environment in Hokkaido. What is concerned here is indoor thermal environment affected by spatial dimension, composition of rooms, insulation performance and the residents’ living style. This study aims to clarify how the room shape and other factors have an effect on indoor thermal environment and to find out the thermal environment characteristics of models of main rooms, such as a living room and a dining room, in contemporary houses in cold climate areas.

## 2. Basic Shape Prototypes of Main Rooms

Eight basic shape prototypes of main rooms in Sapporo were extracted by considering the dimension and “room envelope composition”: the room envelope composition means ceilings and walls are exterior or interior.

This analysis is based on 96 contemporary houses in the Japanese architecture journals, *Shinkenchiku* and *Jutakutokushu* published during 32 years from 1980. The dimension of the main space was examined from the floor area and the height. The average of the floor area was 48.4 square meters and many of the houses were smaller than the average (Fig. 1). Houses with more than two stories was 72 of 96 houses and tended to open toward the perpendicular direction (Fig. 1). In Fig.1 and hereafter, **L** means larger than the average, **S** means smaller than the average, **s** means one story and **h** means two or three stories.

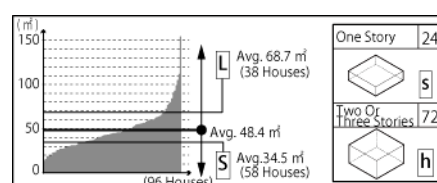


Figure 1. Covered Area and Elevation

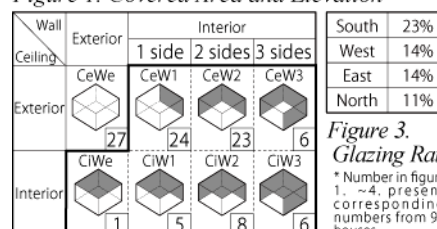


Figure 2. Room Envelope Composition

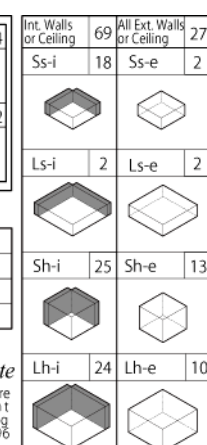


Figure 3. Glazing Rate

Figure 4. Shape Prototype



In addition we considered the dimension together with the room envelope composition (Fig. 2). Hereafter, **e** and **ext.** mean “both walls and ceilings are exterior” and **i** and **int.** mean “more than one part is interior of walls or ceilings”. In Fig. 2, **Ce** means “ceilings and floors are exterior” and **Ci** means “ceilings and floors are interior”. **We** means “walls are exterior”, **Wi** means “walls are interior” and **W1 or 2 or 3** means “one (or two or three) of the walls is (are) interior”. **Ce** was numerous. In contrast, **Wi** was numerous and mostly had an adjacent room in the north side. **Sh**, small area and high elevation, and **Lh**, large area and high elevation, were numerous and **Ls**, large area and short elevation, was not numerous. This shows the tendency to expand to the perpendicular direction, regardless of the area size.

When we focus on the combination of walls and ceilings in terms of exterior or interior, walls and ceilings that are both exterior were the most numerous and there are the examples that the main space occupies most of the floors. In the type of whose walls and ceilings are interior partition, two sides of the five sides were often interior. In addition, floors and walls dividing the main space in small parts was frequently observed. This shows that continuous space is divided into small parts by partitions such as walls and floors. When we examined “glazing rate” meaning windows to wall ratio in every direction, south glazing rate was highest and north one was lowest (Fig. 3). On the basis of such tendency of the dimension and the room envelope composition, main rooms are classified into eight basic shape prototypes (Fig. 4). Most of the patterns have more than one interior part, **i** was most numerous, and **Sh-i** and **Lh-i** were numerous. On the other hand, in the pattern of **e**, whose walls and ceilings are both exterior, **Sh-e** and **Lh-e** were also numerous and this shows the tendency to expand to the perpendicular direction.

### 3. Heat Load of Main Room Models

Changing shape influences heat load as shown in this chapter. The calculation of air conditioning load of each shape prototype at the baseline setting identifies the relationship between the amount of the air conditioning load and shape. To calculate, a PASSWORK design tool named “Solar Designer” was used in this study. Fig. 5 shows the baseline of the setting like climate, months and hours for air-conditioning, months and hours for natural ventilation and building performance. By analyzing annual air-conditioning heat load calculated according to the baseline, the thermal environment characteristic of basic shape prototypes of main room was examined (Fig. 6). When we focus on the room envelope composition, as for the difference of the air-conditioning load, the air-conditioning load of **i** was approximately 20% smaller than that of **e** in any pattern. In addition, when we focus on the dimension, the heat load of **Lh** was the highest, and that of **Ss** was the lowest.

For these, the airspace of **Ls** and **Sh** were almost the same and the heat load of them were almost the same. In all models, the proportion of the cooling load to the whole annual load was much smaller, and the heating load was high especially in a larger airspace. This shows the importance of measures against heating load.

Changing building performance and living style from baseline respectively, influence on the air conditioning load of each shape pattern was examined (Fig. 7). Building performance includes increasing and decreasing insulation performance, additional floor heat storage, and increasing and decreasing glazing rate. Living style includes increasing and decreasing the number of people, an additional nighttime shutter and additional summer green walls. Insulation performance is subject to the present insulation standard "Next Generation Energy-saving standard" revised in 1999.

When we focus on the building performance, as for **×2** and **V-window**, the heat load decreased more greatly than that of the baseline in all the shapes: **×2** means double thickness of insulation obeying the Next Generation Energy-saving Standard and **V-window** means vacuum insulated glass windows. As for **×2**, the heat load greatly decreased in the shapes of **Ss-e**, **Ss-i** and **Ls-e**. As for **V-window**, the heat load greatly decreased in the shapes of **Ss-i** and **Sh-i**. In addition, the heat load decreased in **Glazing -** of all directions especially in the north. Indecreasing the glazing rate of the north in the shapes of **Ss-i** and **Sh-i**, the heat load decreased substantially. In **Mass Floor**, the influence on increase and decrease of the heat load varied according to the shape and the load increased especially in the shape of **Ls**. Against such a technological advance of building performance, the load increased in **Old Standard** with the thickness of insulation obeying "New Energy-saving Standard" (1992), particularly in the shape of **Ss-e**. The heat load increased in **Glazing +** of all directions, especially in the south and in the shapes of **Ss-i** and **Ss-e**.

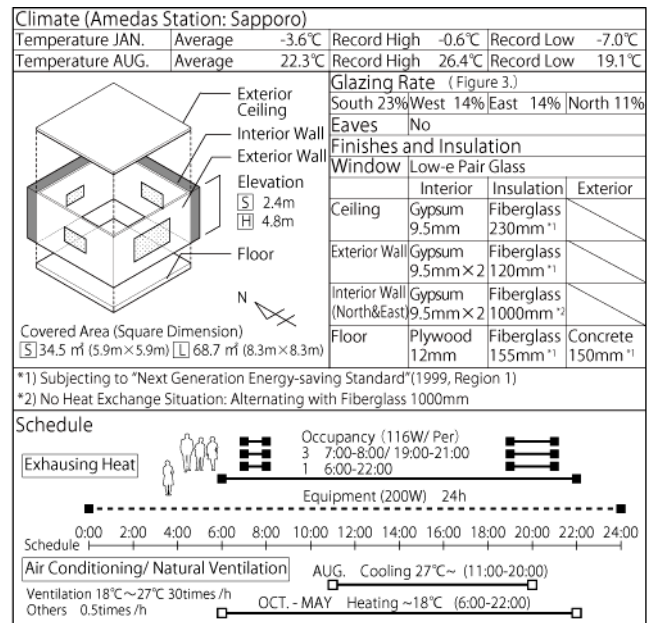


Figure5. Baseline

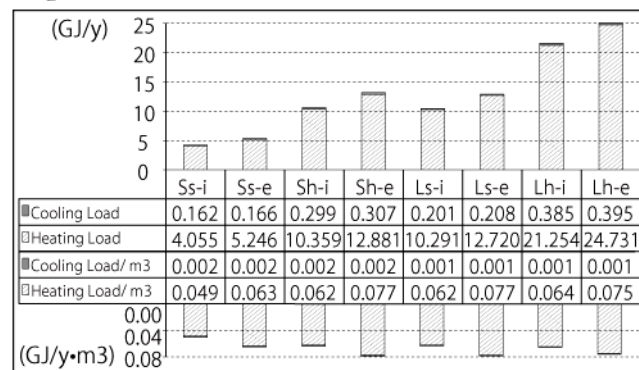


Figure6. Heat Load of Basic Shape Prototypes

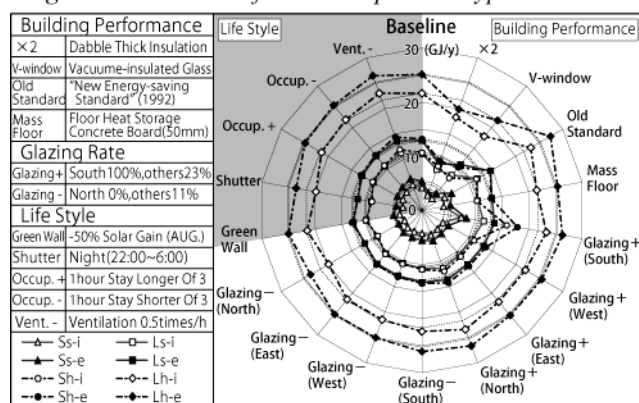


Figure 7. Building performance alternate

When we focus on the life style, the heat load decreased in **Green Wall**, + **Shutter** and + **Occupants**: **Green Wall** means greenery sunshade in August, + **Shutter** means a nighttime shutter and + **Occupants** means three people staying in the place one hour longer. The decrease effect was great in + **Shutter** and in the shapes of **Ss-i** and **Sh-i**. In - **Occupants** and **Vent.** -, the heat load increased: - **Occupants** means three people staying in the place one hour shorter and **Vent.** - means in airtight situation. Small dimension has small energy consumption and the improvement of heat insulation performance, decreasing glazing rate without a south façade and a nighttime shutter restrain energy consumption.

#### 4. Thermal Environment on Main Room Models

The different combination of the setting leads to different inference as shown in this chapter. According to the result of Chapter 3, 48 alternate combinations of building performance and living style are set (Figure 8). The air conditioning load was examined in 48 combination of 8 basic space prototypes.

First, we focus on the difference of the heat gain and loss according to the glazing rate and set + aiming at + **Glazing Rate** with full opening in the south and - aiming at - **Glazing Rate** with no openings in the north. Besides, we set several kinds of thickness of insulation: **O** obeying the New Energy-saving Standard, **P** of the same as the baseline obeying the Next Generation Energy-saving Standard, and that of **×2** is double **P**. That is because the standard of insulation performance varies according to the times. Furthermore, we set additional alternates: **V** means **V-window**, **nS** means + **Shutter**, **V & nS** means **V-window** and + **Shutter**, and **mF** means **Mass Floor**.

Second, we examined the difference of the heat load with the baseline systematically by focusing on the dimension as well as the contrastive characteristics of the spatial shape, such as + **Glazing Rate** or - **Glazing Rate** and **int.** or **ext.** (Figure 9, Figure 10). When we focus on the difference by the insulation performance in every dimension, the heat load decreased in **P** and **×2**, although there were combinations of settings that increased the load, with the insulation thickness of **O** in - **Glazing Rate**. On the other hand, in + **Glazing Rate**, there were combinations that increased the load, though there were many combinations decreasing the load with the insulation thickness of **×2**. Furthermore, in any **Glazing Rate**, when we focus on the difference of **int.** or **ext.**, the heat load of **int.** was lower than that of **ext.**

Furthermore, the heat load of **Ss** was considerably smaller than that of **Lh** with all alternates, when we focus on the difference by the dimension. Besides, the band of the load of **Ss** was approximately half that of **Lh**. In contrast, comparing **Sh** and **Ls**, they have almost the same airspace, particularly in - **Glazing Rate**, the band of the load of **Sh** was approximately twice bigger than that of **Ls**. The heat load increased and decreased according to the airspace. However, the increase and decrease in the heat load changed complicatedly even if they have the same airspace, when the area and the height are different like **Sh** and **Ls**. The bands of the



heat load increased to 1.7-2.5 times depending on the insulation performance by changing only height such as to **Sh** from **Ss**. On the other hand, only enlarging the area like **Ls** from **Ss**, the growth rate of the minimum heat load was at the same level as the change to **Sh**, but the growth rate of the maximum was smaller than **Sh**.

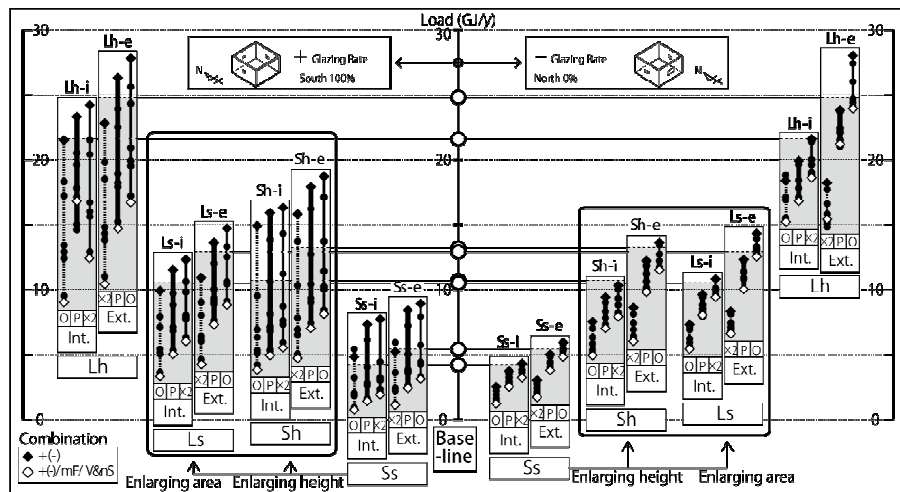
Focusing on the relationship between the dimension and the combination of the settings, effective combinations reducing the heat load were more numerous in a larger airspace. Effective combinations on decreasing the heat load are different even in the same airspace. The tendency was remarkable in **+ Glazing Rate**. We examined the effective combination for the heat load reduction in the shapes of **Ls** and **Sh** in **+ Glazing Rate**, in detail. In the shape of **Ls**, the heat load increased in **+** with the insulation performance **P**, **+** and **O- nS** with the insulation performance **O**. In the shape of **Sh**, there were many combinations increasing the heat load than those of **Ls**. The combinations that increased the heat load were in **“+ with int.”** and **“+ and O- nS with ext.”**, even if the insulation performance is **×2**, except for these combinations, the heat load decreased and **O- mF- V& nS** in **+ Glazing Rate** was the most effective combination by the setting of all shapes including **- Glazing Rate**.

## 5. Conclusions

The present study has demonstrated the thermal environment characteristics of main room models of contemporary houses in Hokkaido. The present result suggested the possibility to make an intimate relationship between indoor and outdoor spaces by using large windows in houses in cold climate areas. Not only insulation but also including spatial dimension and glazing rate affects thermal environment. The load changes according to the size of each area, and the small dimension has small energy consumption. By enlarging only the area size or height, effective combinations for load reduction as well as the range of the load changed the results in complex ways. Though the load increases by increasing only glazing rate, increasing glazing rate with insulation reinforcement and additional thermal mass floor is more effective in reducing energy consumption than decreasing glazing rate.

Few studies have investigated the relationship between form and thermal environment by considering influence on heat load by the combination of shape, insulation performance, and living style, especially in houses in cold climate areas. Therefore, the result of this study will provide new materials about the relationship between the environmental characteristic and the morphological characteristic of contemporary houses in Japan. In this study, we focus on the indoor thermal environment on the housing in the cold climate. The relationship between the environmental characteristic and morphological characteristic in the contemporary houses in different climate regions should be clarified. In addition, considering from different viewpoints from this paper such as natural ventilation, is also important. Further work focusing on these issues is necessary and currently being researched [1,2].

I would like to express my gratitude to Prof. Yuichiro Kodama, Yoshie Matsumoto, Mr. Futoshi Miyaoka for giving insightful comments and suggestions.



**Figure10. Characteristics of thermal environment**



[1] Kisa Fujiwara, Yuko Ono et al. (2014.09). Characteristics of The Thermal Environment of Models of Continuous Spaces of Houses in Tokyo (Part.1), Summaries of Technical Papers of Annual Meeting AIJ

422





## **A critical assessment of the housing sector in Algeria: beyond challenges and opportunities, a sustainable built environment at stake**

**Abstract:** *The term sustainable development includes human development, values and cultures. We are referring to sustainable human development in order to emphasize issues such as the importance of housing quality and participation in decision-making process. Offering many dwellings, the new urban spaces in Algeria are supposed to respond today's population needs, their construction capacity is important, they are aired and endowed of important facilities. But, are they really a place where people want to live, now and in the future? What about urban harmony and wellbeing in this case? We will consider, in this paper, housing projects in Algeria while analysing the new built environments in Algiers, a representative example at the national scale when it comes to housing, with the case of Zerhouni city in particular, one of its nearest and recent suburban area.*

**Keywords:** *housing, built environment, heritage, sustainable development, welfare.*

### **The housing sector in Algeria: which challenges for the decision-makers? Which opportunities for the inhabitants?**

Housing is a basic requirement for everyone. In Algeria, housing shortage gets the political powers to intervene, launching important programs of housing, achieved in the briefest delays. Residential development takes more and more extent in urban periphery. However, housing shortage is far from being resolved. According to the Ministry of Habitat and Urbanism, the first economic plan launched between 1999 and 2003 permitted the realization of 693.800 housings with almost a half million in rental public housing and social-participative housing, with an average cadence of 140.000 housings realized per year. A good performance when one knows that the independent Algeria never passed the rate of 100.000 housings per year. The supplementary programs (1999-2003) recorded more than 1.250.000 housings (32.000 for the South, 37.000 for the High Plateaux and 56.000 various). If the rate of occupation by housing decreased distinctly between 1998 and 2003, while passing from 7.2 to 5.5 people by housing, the situation stayed nevertheless critical.

To face a deficit estimated to 1.1 million of housings, the government announced a new program that spreads from 2005 to 2009 with:

- 24.9% of rental public housing, (a group of block of flats built with public money for low-income families).
- 20.9% of social-participative housing, (this category of housing is based on the claimant's financial participation: 30% advanced by the claimant, 30% as a banking loan and 30% as a non-refundable help from the Algerian State).



- 10.3% of renting-sale housing, (this category of housing allows the claimant to pay his dwelling by easy terms: 10% to begin, 15% when the block of flats is achieved, and the rest payable monthly during 25 years).
- 3.1% of promotional housing, (realized by property developers, promotional housing is characterised by its high quality, its big surface and its good finishes, the access to this private property being truly out of range for a lot of households).
- 40.8% of rural housing, (a group of small homes built with public money to encourage low-income families to stay in the countryside instead of moving to the nearest towns).
- Without forgetting the private housing, otherwise said, the whole individual homes constructed by Algerian citizens by using their own financial means.

The construction of more than one million housings was expected therefore for 2009 by the Ministry of Habitat and Urbanism. The new quinquennial Plan (2010-2014) intended to reinforce the intention of the Algerian State to continue its intense answer to housing demand according to the speech of the President of the Republic. Another million of various categories of housings will be delivered during these five years. The new Prime Minister added last 16 October 2012 that a complementary program of 1.450.000 housings has been launched. In all, 2.450.000 housings will be achieved during this quinquennial.

Today, an intense real estate development advocates a collective habitat. The latter consumes less space and generates collective displacements, articulates itself around a setting aiming all social categories, encourages the diversification of housing models and encourages the participation of citizens. However, the acuteness of the residential crisis doesn't stop persisting despite the efforts of the State to attenuate it. Indeed, 199.653 housings have been delivered in 2009, 179.112 delivered in 2010 and more of 181.829 housings delivered in 2011. In the same way, the Algerian State launches every year new housing projects. Let's mention for instance, the 324.402 housings launched in 2011.

Certainly, good housing strengthens communities and provides a better setting in which to raise families. It improves health, educational achievement and employment opportunities and provides a long-term asset to be passed on the future generations. In order to ensure a better quality of life for everyone, now and for generations to come, it is necessary to renew with larger socials problematic such as to accommodate the population.

But if the territory is a composition that results from strategies of actors, it doesn't stay nevertheless a space socially constructed. Elementary form of territory, housing crystallizes stakes and institutes itself as basis of every projection towards the future. It becomes the object of action of a multiplicity of actors and the topic of different strategies, it is considered under the angle of its materiality and laws that govern it. However, housing is not only a material data. It is constructed by the practices and the representations of individuals. This privileged place of living in which people represent themselves, construct their setting of life, indicates the codes of the society to which they belong, from where the importance of the individual, of the subjectivity, of representations, in every housing analysis. The survey of



the new built environment in Algiers and particularly the new city of Zerhouni, a representative example concerning the housing projects realized in Algeria, will demonstrate the existence of a particular context and the necessity of a set of principles for building the basis of a sustainable built environment.

### **Beyond the housing projects, creating a viable built environment: case of Zerhouni city in Algiers**

These last years, Zerhouni city involved a major transfer of the population guaranteeing everyone the right to a home in optimal living conditions. The city of Zerhouni (called Les Bananiers, otherwise said, Banana trees) is situated in the commune of Mohammadia in the nearest periphery of Algiers and symbolizes a residential zone par excellence. Indeed, Zerhouni city corresponded to a big place of accommodation with rental public housings, social-participative housings, promotional housings and especially renting-sale housings realized by the Housing Improvement and Development Agency (AADL). The agricultural vocation has been completely changed in aid of different housing projects.

#### ***Housing production and inhabitants' comfort***

To build blocks of flats is, for the Algerian decision-makers, a good answer to housing shortage, despite the fact that the inhabitants denounce the formal and architectural poverty of these innumerable buildings of concrete. In Algeria, it appears difficult to escape a repetitive architecture, considering the rigorousness of the economic system of the construction and the constraints due to the prefabrication process. Certainly, housing being above all an object defined by its spatial dimension, it is characterized by three attributes: the metrics, the scale and the substance. Nevertheless, housing constitutes also the concrete matter of the social space and contains the material contexts of the social life.

The treated sample (100 people constituting a representative sample of the inhabitants) is not stratified rigorously, nor completely random. The people were interrogated because of their inscription in the considered spaces and their availability, first condition of the exchange. Let's underline that all the persons that we interrogated lived in Zerhouni city since a few years. Above all qualitative, the committed survey justifies well that it is less the static representativeness and the mathematical rigor that prevail than the capacity to seize the problems that inhabitants meet as individuals and as community in their new built environment. However, the distortions of the sample owed to absences or refusals are frequent. Cases of non answers can also depend on the asked questions, of the implication level of the interrogated people and of their socio-cultural features. The results have been interpreted while using the software Sphinx version5.

In our investigation, 70% of the interrogated inhabitants were tenants and 30% owners of their housing. A big majority of the investigated find their housing suitable (70% of the investigated) or even agreeable (65% of the investigated). Therefore, only 35% of the investigated find their housing disagreeable and only 30% find it narrow. However, the



inhabitants delighted, in a first time, to find in these apartments modern comfort of which they had been deprived until then, mentioned subsequently problems of bad workmanship, not waterproof roofs and bad plumbing. This kind of problems comes back constantly to the centre of proceedings. This fact reflects the state of emergency of construction operations and of assignment of housings.

Indeed, Zerhouni city has been achieved gradually following a general plan, in order to realize a coherent assemblage of different types of architecture and dwellings. Urban planners thought that a satisfactory life quality got itself thanks to a strong population density, solely capable of guaranteeing services, transportation and animation of the district. Therefore, the will to arouse a feeling of city, to create an animation, results in invariable characteristics: the high density of housings, the presence of facilities; the whole lot connected by public transportation. But today, as the city tries to define its role, it undergoes periodic adjustments. Did the local authorities ensure a balanced situation on the social as well as the economic plan by realizing close to those residential spaces public facilities and transport services?

### ***Facilities offer and inhabitants' practices***

The residential life, work, purchases, leisure and activities take place henceforth in separated places, within agglomerations always more vast. If this picture is also worth for Algiers and its suburban areas, the more active families disperse themselves daily between different places. To satisfy the basic needs of the inhabitants of Zerhouni city and to achieve a better quality of life in this new built environment, planners put in service scholar facilities since the arrival of the first inhabitants. These last, find close to them, primary schools, colleges and trades of first necessity. While moving a little away, they reach high schools. By bus, they can join the banks, the universities and the hospitals. It was the diagram that prevailed in the entire city.

Nonetheless, this fact doesn't prevent the investigated to mention the lack of life. Indeed, the interrogated find their new district un-lively and monotonous (60% of the investigated), and 69% of the investigated don't like the city. For these inhabitants, to lodge is necessary, but not sufficient. Around that, they expect to find a district, with its exchanges, a city full of life. According to the interviewed – the identity of the interviewed will not be unveiled in this paper, anonymity being thus respected – what was missing lies in: «places of meetings and exchanges, crowded day and night [...] places edged with boutiques [...] a market where to go shopping».

Today, taking into consideration the social disparities and lifestyles, makes feel itself more and more. The worry of the proximity of trades, for example, is raised by the modest populations, in particular by the non-motorized people. The supplying of appropriate public services implied a great concern too. The absence of a local post office, for instance, is not practical for retired people who are obliged to go at least 10 kilometres away to get their pays. Is the new built environment badly connected with good transport services linking people to jobs, schools, health and other services?



### ***Transportation means and inhabitants' interests***

In Zerhouni city, the transport system suffered from overcrowding, congestion, delays, pollution and everyone could easily observe a predominance of individual vehicles demonstrating a lack of choice over how to travel. The planning operations were put back notably because they granted the collective space a unique vocation: the automobile circulation. The inhabitants needed a step change in transport planning in order to deliver a system which meets the needs of all of them, because that one does want it or not, a good transport system is essential both for a strong economy and a better quality of life.

Today, a new line of Tramway links this city to the downtown of Algiers and also to the nearest communes: A first section of 7.2 Km in lengths linking Bordj El Kiffan commune to Zerhouni city (both situated in the Eastern part of Algiers) has been put in service on the 8<sup>th</sup> of May 2011. It has been extended with 9 other kilometres to "The Executed by firing squad" Multimodal Station in the downtown area this time. This second section has been put in service on the 15<sup>th</sup> of June 2012, offering principally an interconnection with the subway. In total, the tramway line spreads actually over 16.2 Km with 28 stations. A third section from Borj El Kiffan commune towards Dergana commune (always in the Eastern part of Algiers) is currently under construction and will be opened soon.

For the inhabitants, the displacements to Algiers are indispensable for reasons as working, shopping or visiting family, but the observation of the places which are frequented for other reasons demonstrates that it is never very distant from the district of origin. Actually, the frequent round trips between the previous and the actual place of residence don't permit to speak about two distinct territories. On the one hand, in the time, since one corresponds to the past, bygone, and the other to the present and to the future, and on the other hand, in the space, seeing that to each one correspond representations and practices spatially determined. Does this change of district imply a change in lifestyles or community behaviours?

### ***Setting of life and inhabitants' safety***

Rehoused by the local authorities, some inhabitants are from the central districts of Algiers as well as from its shanty towns. For a lot of households, these districts are the places of their installation since their arrival to Algiers. The residential transfer to Zerhouni city provokes material and symbolic effects. For the inhabitants, the modification of the territorial system consists of a new type of housing (apartments in towers or bars), a new lifestyle, a new spatial configuration of the private space, a new use of the public space, without forgetting the new geographical situation, which implies some new norms to fit. While observing the inhabitants of Zerhouni city and what they had converging, while admitting their oddness appeared "common features" like the installation in the city, the learning and the experimentation of the new housing, but again and especially the residential stability in Algiers, from where the importance of the opinion of these persons.



According to the investigation, 77% of the interrogated inhabitants find Zerhouni city troubling. According to the interviewed coming from the medina: «The city is worrying [...] the strong presence of people coming from shantytowns justifies this judgment». Indeed, this population is judged socially «undesirable» and the local authorities must be attentive to the evolution of this hostile attitude towards poorest inhabitants. Moreover, the observation of the extra-curricular activities in Zerhouni city, demonstrates that children and teenagers remain near to their building or go to playgrounds. According to the interviewed, what was missing lies in: «sports rooms opened till late [...] a garden where to stroll or to eat lunch, well planted trees, correctly fixed lamps, all that has been neglected, from where the necessity of qualitative interventions in order to improve the well-being in Zerhouni city».

Let's underline that public spaces constitute a permanent element of the urban environment, at the same time for inhabitants and passers-by. Inhabitants spread around their housing, they refer to the district, pay a particular attention to streets, places, centres and settings of their daily life. Therefore, a reflection on the space must facilitate the establishment of social relations between inhabitants and also of neighbourhood.

In Zerhouni city, the built homogeneity is defined by its identical blocks signalling paradoxically who lives there and why, and unveiling the social group heterogeneity. Creating buildings and urban environment that people enjoy living in and working in requires therefore, best practices at the same time economic, social and environmental. Building and strengthening a sustainable community imposes as well, to improve the quality of life of the population and to consider the longer term implications of decisions.

«The possibility to identify us positively to a place [...] to develop the pride to live in», this is the essential stake for the new residents. Indeed, beyond the simple addition of housing, of services, of streets, the city defines itself by its character and its quality, the animation, life that results from the combination of all these elements. Currently, the space inhabited also represented and lived, namely Zerhouni city, defines itself from its social actors, their representations, their behaviours and their practices. Certainly, the identity forms the major tie between the human beings and their setting of life. It is a powerful motor of social production. Nevertheless, that appropriation process deserves to be shaded. The experimentation of this new built environment imply, according to the inhabitants, some new attitudes, some new behaviours to adopt.

## Conclusion

The reflection on the new built environment in Algiers leads to the definition of the pros and cons, to a hold of position towards these big housing programs and the challenge that they raised. For the present as for the future, the local authorities must learn to put the inhabitants first, not fees or speed of construction, while going beyond the simple information of the population, while accepting to approach "topics that annoy", while admitting the contradiction and while accepting to be disavowed sometimes, because that they do want it or not, the



adherence of citizens to projects that concern them is, in the present context, the key of a sustainable built environment.

The analysis of our investigations and interviews indicates that the representations of the residential spaces of the inhabitants depend closely on their experience at the same time personal, social and spatial. Consequently, constrained by inhabitants' attitudes, housing projects cannot conceive themselves outside of their context and must define themselves according to the will of the local actors and their prerogatives certainly, but also and especially according to the inhabitants needs.

Today, for a sustainable built environment, a broad view of inhabitants' welfare is necessary, a long term perspective about the consequences of today's actions of the Algerian decision-makers is required and the full involvement of civil society to reach viable solutions is becoming more than ever imperative. That's why all citizen participation must be significant, committed and constructive.

## References

- Di Meo, G., & Buleon, P. (2005). *L'espace social, lecture géographique des sociétés*. Paris : Armand Colin.
- Jean, Y., & Calenge, C. (2002). *Lire les territoires*. Tours: MSH.
- Makhloufi, L. (2010). Inhabitants/Authorities: a Sustainable Housing at Stake. Case of: Ali Mendjeli new town in Constantine. In S. Lehmann & H. Al Waer & J. Al-Qawasmi (Ed.), *Sustainable Architecture & Urban Development, SAUD 2010*, Volume1/4, (pp.367-383). Amman: The Center for the Study of Architecture in the Arab Region & University of Dundee (UK).
- Makhloufi, L. (2009). Socio-economic issues in Constantine: which contexts for which consequences on the sustainable urban development? In S. Fortea & J. Al-Qawasmi (Ed.), *Sustainable Architecture and Urban Development, SAUD 2009*, Volume1/2, (pp.367-381). Amman: The Center for the Study of Architecture in the Arab Region & University of Tripoli.
- Makhloufi, L. (2009). Le logement comme moteur du développement territorial en Algérie : quels défis ? Quelles opportunités ? In C. Mager (Ed.), *Développement territorial : jeux d'échelles & enjeux méthodologiques*, (pp.141-148). Lausanne : Observatoire de la ville et du développement durable.
- Makhloufi, L. (2007). Identity in Transition: Residential Spaces Undergoing Profound Conceptual Change - Case of: Ali Mendjeli new town. In J. Al-Qawasmi & A. Mahmoud & A. Djerbi (Ed.), *Regional Architecture and Identity in the Age of Globalization*, Volume1/3, (pp. 271-284). Amman: The Center for the Study of Architecture in the Arab Region.
- Regional Environmental Center for Central and Eastern Europe. (2009). *What is a sustainable city?* Available at: <http://www.rec.org/REC/Programs/Sustainablecities/What.html>
- Thibaud, J-P. (dir.) (2007). *Variations d'ambiances. Processus et modalités d'émergence des ambiances urbaines*. ENSA Grenoble : CRESSON Laboratory.

## Life Cycle Analysis of standard and high-performance cements based on carbon nanotubes composites for construction applications

Matanza, Amaia<sup>1</sup>, Vargas, Gustavo<sup>1</sup>, Leon, Iñigo<sup>1</sup>, Pousse, Maxime<sup>2</sup>, Salmon, Nicolas<sup>2</sup>, Marieta, Cristina<sup>1</sup>

<sup>1</sup> EUPD (UPV/EHU), Plaza Europa 1, 20018 Donostia-San Sebastián, Spain

<sup>2</sup> NOBATEK, Rue de Mirambeau, 64600 Anglet, France

**Abstract:** Research of new cement formulations is of outstanding interest for satisfying the new requirements in architectural and infrastructure projects safely, affordably and sustainably. Addition of nanofiber reinforcement to different matrices allows the crack growth control at nanoscopic scale, creating a whole new generation of crack-free materials. Among these new nano-reinforcements, the carbon nanotubes (CNTs) deserve to be highlighted considering that the addition of CNTs to cement leads to high-tech formula. Thus, high-performance cements based on carbon nanotube are being researched. However, the literature indicates considerable variability and uncertainty regarding the health impacts, reactivity, ecological effects, and environmental fate and transport of CNTs. Therefore, it is necessary to analyse how the addition of CNTs may affect the environmental profile of cement. This study evaluates hypothetical high-performance cements based on carbon nanotube reinforcement with a Life Cycle Assessment (LCA) in order to compare the environmental impact of these new developments with traditional cements. The results of the study indicate higher life cycle requirements and higher environmental impact of high-performance cements based on carbon nanotube composites as compared to traditional ones.

**Keywords,** Cement, CNT, Life Cycle Assessment

### INTRODUCTION

It has been estimated that over 50% of the annual European construction budget is spent on the repair and refurbishment of existing structures, buildings and facilities [1]. Thus, the repair of deteriorating reinforced concrete structures is an important part of the global construction market. Moreover, the requirements in new architectural projects and civil infrastructure are more and more exigent. Therefore, new materials are needed for satisfying the new demands in a safe, affordable and efficient way.

At the beginning of the 21<sup>st</sup> century, the fast-emerging field of nanotechnology sparked a high level of interest from the scientific and industrial communities, and today, nanotechnology is being applied to almost every facet of modern life, and it is also revolutionizing the conventional construction materials: cement, concrete and wet mortar. In this way, for example, belonging carbon nanotubes (CNTs) to the new class of superior engineered materials because of their exceptional mechanical properties, Raki et al. reported that CNTs can improve the hardness of the early hydration of the cement-based material by 600%, the Young modulus by 227% and the flexural strength by 40% [2]. Veedu incorporated 0,02 wt% CNTs into the cement-based materials to make its flexural and compressive strength increases by 30% and 100% [3]. However, it remains a significant lack of information regarding the health effects and environmental impacts of CNTs as well as how the addition of CNTs may affect the environmental profile of products. Given these uncertainties, it is of interest to carry

out the Life Cycle Assessment (LCA) of these cements with CNTs to track the environmental impacts through their fabrication and to compare with those of the traditional cements. For developing the study, the life cycle inventory and the results of CNT's assessments from the open literature have been used. Concretely, as carbon nanofibers have similar manufacturing methods with comparable impacts to CNTs [4], the results reported by Khanna for a cradle-to-gate LCA of vapor-grown carbon nanofibers have been used [5].

## METHODOLOGY

Environmental evaluation of the cements is carried out using a process-based life cycle assessment methodology with distinct stages to generate a comprehensive overview of the product's total environmental effect: Goal and Scope definition, System Boundaries and Life Cycle Inventory and Data collection and Impact Assessment Method. This is a "cradle-to-gate" LCA that includes upstream inputs such as raw materials extraction and processing of the input materials and energy as well as the inputs and emissions associated with fabrication. LCA results have been obtained by using Simapro 8.0.1 software and CML-IA baseline v3.00 method.

## LIFE CYCLE ASSESSMENT

### Goal and Scope

The goal of this study is to measure the environmental impact of hypothetical high-performance cements based on carbon nanotube reinforcement. Firstly, an ordinary Portland cement of the region (CEM I 52,5 N of FYM Italcementi Group, Añorga, Guipuzcoa, Spain) is evaluated. The functional unit is 1 t, since it is recommended in the appropriate Product Category Rules, PCR, according to ISO 14025:2006 [6].

### System Boundaries and Life Cycle Inventory

The system used in this study is the production system of 1 t of CEM I, ordinary Portland cement. This type of cement is selected as it is composed with 93,5% by mass of clinker, primary reactive compound, which has the highest environmental impact due to kiln operation. Main processes of the system are: 1) extraction and crushing of raw materials, mostly obtained from their own quarries: limestone and calcareous marl; 2) clinker production, grinding of raw materials and running of kiln; 3) cement production, mixing and grinding with limestone and gypsum. The system finishes in factory's gate, when cement is ready for delivering, only considering storage in plant's silos.

Limestone quarry is 8 km away from the factory and calcareous marl quarry is next to it. Sand, gypsum and other additions quarries or providers are situated at maximum of 200 km from cement plant. Therefore, transport of raw materials is only done by freight lorry. Primary fuel of clinker kiln is petroleum coke, although also municipal and tyre waste are burned, they can be considered as coke saving. Heavy fuel is only used to start the kiln after a technical or programmed stop.

After raw mill, blending and weighing processes take place. Clinker kiln is preceded by a preheater cyclone tower which helps saving fuel as raw materials do not enter completely cold. After kiln there is a grate cooler with bag filters and heat exchanger.

CEM I Portland cement produced in Añorga (Spain) consists of 93,5% of clinker, 3,5% of gypsum and 3% of owned quarry's limestone. Complete life cycle inventory, LCI, of the cement production is showed in Table 1. All emission to water and air are also included in LCI table of clinker (Table 2).

Inputs	Amount
Clinker	0,935 t
Gypsum, mineral	0,035 t
Limestone, crushed	0,03 t
Cement factory	5,36E-11 p
Tap water	24,53 kg
Water, natural origin	0,925 m <sup>3</sup>
Ethylene glycol	4,89E-04 kg
Steel, low-alloyed	0,116 kg
Electricity, high voltage, national mix	24 kWh
Outputs	
CEM I 52,5 N	1 t
Heat, waste	0,135 MJ
Water	0,804 m <sup>3</sup>

Table 1: LCI of CEM I 52,5 N of Añorga's plant, FYM Italcementi Group

Inputs	Amount
Limestone, crushed	733,3 kg
Calcareous marl	254,6 kg
Sand	4,7 kg
Iron ore waste	7,4 kg
Petroleum coke	96,45 kg
Heavy fuel oil	1,73 kg
Municipal solid waste	1,065 kg
Inert waste, used tyres	17,44 kg
Refractory, fireclay	0,71 kg
Ammonia, liquid	3,75 kg
Cement factory	6,27E-12 p
Industrial machine	3,76E-05 kg
Lubricating oil	4,71E-05 kg
Steel, chromium steel 18/8, hot rolled	5,86E-05 kg
Electricity, high voltage, national mix	29,08 kWh
Emissions	Amount (kg)
Antimony	2E-09
Nitrogen oxides	1,03878944
Tin	9E-09
Zinc	7,6085E-05
Carbon dioxide, biogenic	0,01509999
Mercury	3,3E-08
Thallium	4,2952E-06
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	9,6E-13
NMVOC, non-methane volatile organic compounds	0,01367143
Methane, fossil	8,88E-06



Copper	1,7184E-05
Cobalt	4E-09
Sulfur dioxide	0,09841769
Hydrogen chloride	0,00362583
Nickel	2,1833E-06
Arsenic	1,2E-08
Carbon dioxide, fossil	735,230754
Particulates, unspecified	0,06177276
Lead	9,6812E-06
Carbon monoxide, fossil	1,13869346
Vanadium	5E-09
Ammonia	0,00483087
Beryllium	3E-09
Chromium	1,4095E-05
Selenium	2E-09
Cadmium	7E-09
Manganese	1,0893E-05
Hydrogen fluoride	0,0009762
VOC, volatile organic compounds	0,00940606
Benzene	4,527E-05
Nitrogen monoxide	0
Anthracene	1,2058E-06
Naphthalene	4,042E-05
Hydrogen cyanide	0,00010445

Table 2: LCI of clinker produced in Añorga's plant, FYM Italcementi Group

#### Data collection and Impact Assessment Method

According to PCR, data concerning clinker and cement composition, as well as energy consumption, were kindly provided by the producer, manufacturing plant in Añorga, Spain. Likewise, data concerning transports, raw materials, fuels and atmospheric emissions were mostly provided by producer and normalized for the functional unit. Data concerning infrastructure are taken from Ecoinvent Database [7]. The producer has provided one year averaged data, from 2013 period. For the electricity used in cement factory, national electricity mix was obtained from 2013 monthly evaluation report of Red Eléctrica Española (Spanish Electric Net) [8]. Transport of raw materials is counted in terms of the capacity of the vehicle and the length of the routes travelled. Recycled waste used as alternative fuels is considered, in 2013 the clinker kiln burned 5405 tons of municipal and tyre waste.

According to PCR, environmental impact categories to consider in life cycle assessment are: Global Warming, Ozone Depletion, Acidification for soil and water, Eutrophication, Photochemical oxidation, Depletion of abiotic resources (for fossil fuels and for non-fossil resources).

#### CNF and CNT reinforcements LCA

The manufacturing cycle of CNF or CNT nanoproducts includes three stages: 1) raw material acquisition (depending on carbon source used), 2) synthesis and 3) purification. Raw materials needed are carbon precursor material (methane, ethylene or benzene considered as carbon sources); catalysts, solvent, hydrogen gas and sulphur sources for the reactor. There

are four routes to synthesize CNTs, namely chemical vapour deposition, electric arc discharge, laser ablation and high pressure carbon monoxide process. For purification stage, there are also different techniques: air oxidation at high temperatures, refluxing with acids, sonication and annealing, and microwave-assisted purification. 1 kg of purified CNF or CNT is the functional unit for this cradle-to-gate life cycle assessment. The manufacturing stage is energy-intensive process; raw materials used in the reactor have associated high toxic emissions or waste; operation temperatures are very high. Therefore, environmental impacts obtained will overcome traditional construction materials.

As considered by Upadhyayula et al. [4], CNF and CNT nanomaterials have similar manufacturing methods, data are obtained from a cradle-to-gate LCA reported by Khanna et al. [5] of a vapour-grown carbon nanofibers (VGCNFs). This method can provide of a continuous scale synthesis, which is appropriated for industrial products.

VGCNFs are produced by catalytic pyrolysis of hydrocarbons. A sulphur source is added to promote the formation of CNFs. As catalyst source, ferrocene ( $C_{10}H_{10}Fe$ ) is dissolved in a suitable solvent (hexane). Temperature reaches  $1100^{\circ}$ - $1200^{\circ}$  C in the electric furnace. Hydrochloric acid is the acid used in purification stage. Total energy required for the process includes all stages: manufacturing and purification.

It has been considered that the amount of CNT is 0,75 wt% of dry cement, which is the needed amount to increase the flexural strength by about 88% [9].

## RESULTS AND DISCUSSION

LCA results for the CEM I 52,5 N are presented in Table 3. Analysing the responsibility of each fabrication process for each impact category (Figure 1), it can be highlighted that clinker is 80% responsible of the impact in all of them, except for Terrestrial ecotoxicity in which it is responsible for 55% of the environmental impact. In that category, high voltage electricity supplying is the second responsible of the impact.

Impact category	Unit	Amount
Abiotic depletion of resources	kg Sb eq	2,18E-04
Abiotic depletion of fossil fuels	MJ	1.484,5
Global warming, GWP	kg CO <sub>2</sub> eq	749
Ozone layer depletion, ODP	kg CFC-11 eq	7,58E-06
Human toxicity	kg 1,4-DB eq	66,584
Fresh water aquatic ecotox.	kg 1,4-DB eq	36,024
Marine aquatic ecotoxicity	kg 1,4-DB eq	100.751
Terrestrial ecotoxicity	kg 1,4-DB eq	0,827
Photochemical oxidation	kg C <sub>2</sub> H <sub>4</sub> eq	0,056
Acidification	kg SO <sub>2</sub> eq	1,006
Eutrophication	kg PO <sub>4</sub> <sup>2-</sup> eq	0,222

Table 3: LCA results. Environmental impacts to produce 1 ton of cement CEM I 52,5 N.

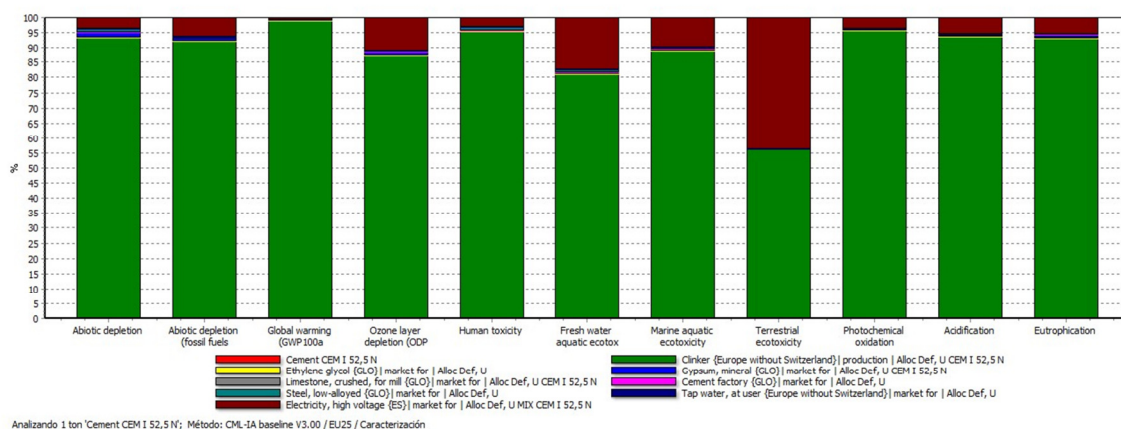


Figure 1: System boundaries and processes of the Añorga's cement plant.

In order to get a better insight in the environmental performance of the CEM I 52,5 N cement under study, a comparison with other similar LCA studies has been performed. The comparison has been performed on four environmental impact categories required by the cement Product Category Rules (CPC Class 3744 CEMENT, 2010:09), namely Global warming, Photochemical oxidation, Acidification and Eutrophication. Other environmental impact categories of the PCR (i.e. abiotic depletion impact categories and ozone depletion) have not been included because their calculation methodology differs between the different sources (e.g. aggregation of abiotic depletion indicators...). Main methodological points of LCA studies in the comparison are given in Table 4. From a general perspective, although some of these studies used different LCA methodological standards, the comparison is possible and relevant because all the presented LCA standards are based on the CML characterisation method [10]. Therefore, although some slight differences can be observed between the different versions of CML used in the different LCAs, the comparison is relevant. Figure 2 shows the results observed in these different LCA studies.

Study	Product	Scope	Functional unit	LCA methodological standard	Geography
Current study	CEM I 52,5 N	Cradle-to-gate	1 t	Cement PCR	Spain
ATILH, 2011	Portland CEM I 52,5 N et 52,5 R	Cradle-to-gate	1 t	NF P 01-010 (source)	France
ECOCCEM, 2008	Portland cement (CEM I)	Cradle-to-gate	1 t	Cement PCR	Ireland
Nesher, 2014	CEM I 52,5 N	Cradle-to-gate	1 t	Cement PCR	Israel

Table 4: Main methodological points of LCA studies used in the comparison.

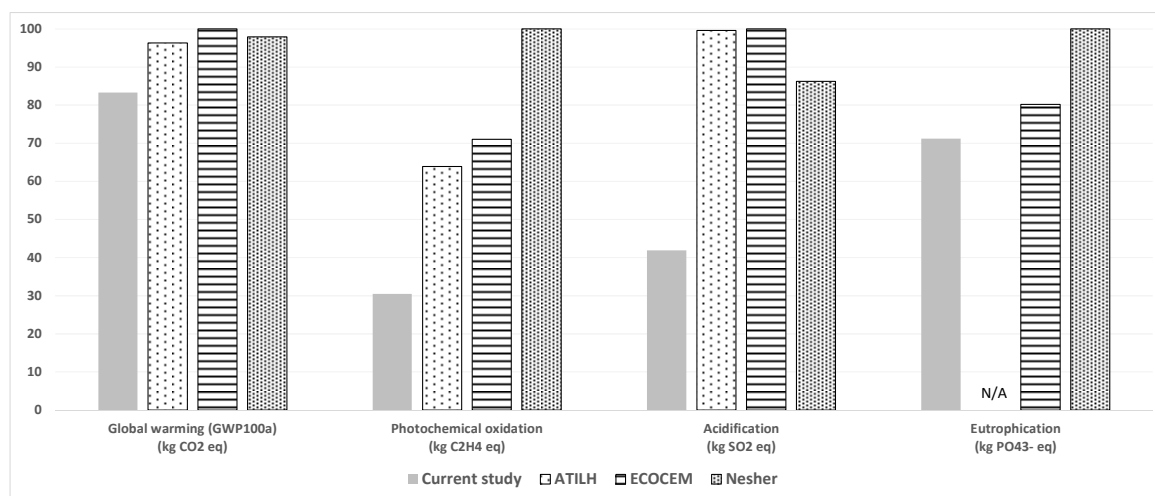


Figure 2: Comparison of LCA results with other similar LCA studies. For each impact category, the highest results is set to 100, other results are scaled accordingly.

As can be seen, the potential environmental impacts associated with the cement under study are lower than environmental impacts calculated in other LCA studies. This fact is attributed, on the one hand, to the lower distance of transportation of raw materials for the CEM I 52,5 N, and on the other hand, to the fossil fuel used for its fabrication.

In table 4 comparative impacts of the CEM I 52,5 N and reinforced cement are shown.

Impact category	Unit	1 kg CEM I 52,5 N	1 kg reinforced cement
Abiotic depletion of resources	kg Sb eq	2,184E-07	8,642E-06
Abiotic depletion of fossil fuels	MJ	1,485	56,719
Global warming, GWP	kg CO <sub>2</sub> eq	0,749	4,528
Ozone layer depletion, ODP	kg CFC-11 eq	7,588E-09	6,396E-07
Human toxicity	kg 1,4-DB eq	0,067	1,353
Fresh water aquatic ecotox.	kg 1,4-DB eq	0,036	3,384
Marine aquatic ecotoxicity	kg 1,4-DB eq	100,751	5985,378
Terrestrial ecotoxicity	kg 1,4-DB eq	0,00082736	0,18839807
Photochemical oxidation	kg C <sub>2</sub> H <sub>4</sub> eq	5,5717E-05	0,00125085
Acidification	kg SO <sub>2</sub> eq	0,00100558	0,03213931
Eutrophication	kg PO <sub>4</sub> <sup>2-</sup> eq	0,00022225	0,00745367

## CONCLUSIONS

The major conclusion that we can draw is that the inclusion of CNTs increases considerably the environmental impact of cement production. Besides, progress in research on these kinds of systems is largely hampered by the intrinsically hydrophobic nature of CNTs and their chemical incompatibility with cement hydrates. Thus, we propose new alternatives to CNTs as reinforcement for cements such as inorganic nanotubes or plastic nanofibers.

## REFERENCES

1. Retrieved from <http://carboninspired.com/blog/?p=416&lang=en>



2. Raki, L. Beaudoin, J. Alizadeh, R. et al. (2010). Cement and concrete nanoscience and nanotechnology. *Materials*, 3(2):918:942, [doi:10.3390/ma3020918](https://doi.org/10.3390/ma3020918)
3. Veedu, V. P. (2011) Patent 7875211[P].
4. Upadhyayula, V. K. K. Meyer, D. E. Curran, M. A. Gonzalez, M. A. (2012). Life cycle assessment as a tool to enhance the environmental performance of carbon nanotube products products: a review. *Journal of Cleaner Production*, 26:37-47, [doi:10.1016/j.jclepro.2011.12.018](https://doi.org/10.1016/j.jclepro.2011.12.018)
5. Khanna, V. Bakshi, B. R. Lee, L. J. (2008). Carbon Nanofiber Production. *Journal of Industrial Ecology*, 12(3)394:410, [doi:10.1111/j.1530-9290.2008.00052.x](https://doi.org/10.1111/j.1530-9290.2008.00052.x)
6. EPD, Product Group: UN CPC 3744 Cement, 2014-02-17. Product Category Rules according to ISO 14025:2006
7. Ecoinvent Database v3.0, Swiss Centre for Life Cycle Inventories
8. Monthly evaluation report, Decembre 2013, number 84, 2014-01-28. Red Eléctrica Española, [www.ree.es](http://www.ree.es)
9. Hunashyal, A. M. Lohitha, S. J. Quadri, S. S. Banapurmath, N. R. (2011). Experimental investigation of the effect of carbon nanotubes and carbon fibres on the behaviour of plain cement composite beams. *IES Journal Part A: Civil & Structural Engineering*, 4(1):29-36.
10. Guinée J.B., Gorée M., Heijungs R., Huppes G., Kleijn R., de Koning A., van Oers L., Sleeswijk A.W., Suh S., Helias A., de Haes U., de Bruijn H., van Duin R., Huijbregts M.A.J., Life cycle assessment, An operational guide to the ISO standards, Centre of Environmental Science – Leiden University (CML), 2001.



## **A Building Products Procurement Platform for Environmental Evaluation of Design Alternatives**

### **Authors:**

Parsanezhad, Pouriya<sup>1</sup>; Malmqvist, Tove<sup>2</sup>; Tarandi, Väino<sup>3</sup>; Falk, Örjan<sup>4</sup>; Paul, Prabin<sup>5</sup>; Cvetkovic, Vladimir<sup>6</sup>

<sup>1</sup> KTH Royal Institute of Technology, Stockholm, Sweden

<sup>2</sup> KTH Royal Institute of Technology, Stockholm, Sweden

<sup>3</sup> KTH Royal Institute of Technology, Stockholm, Sweden

<sup>4</sup> KTH Royal Institute of Technology, Stockholm, Sweden

<sup>5</sup> Teknocord AB, Stockholm, Sweden

<sup>6</sup> KTH Royal Institute of Technology, Stockholm, Sweden

**Abstract:** *This work provides the basis for developing a building products procurement platform for environmental evaluation of design alternatives. The outcome is a ground for implementing existing tools and standards for life cycle assessment or environmental certification of buildings in the early building design stage.*

*For this purpose, the first phase of the Life-cycle-support Building product Indexing Platform (Lcs-BIP) project is reported and demonstrated for a specific user case, procurement, through a workflow scheme. The federated solution introduced for environmental evaluation of design alternatives is composed of a web-based tool for life-cycle-support building procurement, coupled with a BIM-enabled platform and data sharing hub. The system assists users to maintain a trifold focus on competitive price, quality, and environmental performance of the building. The overall workflow of the system is explained through an exemplar scenario with the three disciplinary roles of an architect, a BIM administrator and a contractor.*

***Life cycle assessment, Building Information Modelling, Environmental Product Declaration, procurement, IFC***

### **Introduction**

Advert of Building Information Modelling (BIM) [1] tools has envisioned promising prospects for a more realistic sustainability approach towards design and construction [2]. BIM is, in principle, a “modeling technology and associated set of processes to produce, communicate, and analyze building models” [3]. BIM facilitates integration of a wide variety of product and material specifications into the building model early in the design and procurement phase which, in turn, opens up plausible possibilities for various types of environmental analyses of a multitude of design alternatives in a fast and automated fashion.

Implementation of BIM tools and methodologies by different actors across the construction industry has continually gained momentum in recent decades. According to a report by McGraw Hill Construction, 71% of architects, engineers, contractors and owners in North



America have been engaged with BIM in 2012; which demonstrates a 75% increase over five years [4]. An earlier report shows that 60% of total respondents in Western Europe have been using BIM on at least 30% of their projects in 2010; while the steepest anticipated implementation curve in the ensuing years among different user groups belonged to contractors [5]. In Sweden, 46% of construction companies were using BIM towards the end of 2011 and 53% had planned to increase their levels of BIM implementation in the future [6].

Nonetheless, problems such as availability of product specific environmental data, data format mismatch and incompatibility of design and analysis tools with product specification documents and databases, now prevailing in the market, has proved to be a major obstacle. One of the initiatives for coping with interoperability problems is the Industry Foundation Classes (IFC) format. IFC is a vendor-neutral and object-based building data model (IFC-ISO/PAS 16739) for capturing building information in a standard way indifferent of the proprietary authoring tools deployed [7]. However, according to a recent survey performed on a number of IFC-compliant environmental analysis software solutions, none of them were fully capable of performing sustainability analysis [2]. The reason was that: a) none of those applications included all the indicators required for sustainability analysis; b) transfer of the building geometry from the CAD (Computer-Aided Design)/BIM tools to most of those applications had to be done manually; and c) modification of the design models with regard to the feedback from energy simulations was not fully automated (it was not possible to import the results back to the design tool). The software packages studied in the survey were Archiwizard, EcoDesigner (an extension to ArchiCAD), ECOTECT (developed by Autodesk), ELODIE (developed by CSTB), IDA ICE, ILMARI (developed by VTT), Green Building Studio (also by Autodesk), Fide and TRNSYS.

To address similar problems was the starting point for the interdisciplinary applied research project, Life-cycle-support Building product Indexing Platform (Lsc-BIP) executed at BIM Collaboration Lab at KTH.

### **Aim**

In this paper, the first phase of the above-mentioned Lcs-BIP project is reported and demonstrated for a specific user case, procurement, through a workflow scheme. This work forms the basis for developing a federated solution performing as a building products procurement platform for environmental evaluation of design alternatives. The outcome of this study is a ground for implementing already existing tools and standards for life cycle assessment or environmental certification of buildings in early building design [8].

### **General Configuration**

The outcome of the first phase of the Project is a set up composed of two major component systems: a web-based tool for realizing a life-cycle-support building procurement, BuildX; coupled with a BIM-enabled knowledge management platform and data sharing hub, Share-A-space.



The former envisions web-based communication linkages with both local and international manufacturers of building products and maintains a trifold focus on competitive price, quality measures, and environmental performance. This user-friendly and informative interface eventually builds up an ever-updated interactive database of downstream product specifications using ISO formats such as Environmental Product Declaration (EPD) [9] when provided by product manufacturers. However, since EPDs still are lacking for most building products, the application offers a simplified and transparent calculation (EPD-estimator) integrated in the product database, to generate product-specific environmental data. The tool provides cradle-to-grave CO<sub>2</sub>e emission data with the option for the manufacturer to select conservative default values if any product input data is missing.

The latter, on the other hand, receives building models from in the IFC format. This enables eliciting models from different actors who deploy diverse proprietary BIM-authoring tools for compiling design alternatives. Share-A-space (S-A-s) then implements the PLCS standard (Product Life Cycle Support - ISO 10303-239) internally to maintain a through-life-support approach to building knowledge management [10]. The PLCS format has the capacity to capture and retrieve all the changes that occur in the building information database over time; while the content of an IFC model is merely a cross-section of the ever-evolving building model at a certain point in time.

### Scope and Delimitations

To illustrate the methodological solution clarified above, a proof-of-the-concept demonstration case was built up for a specific user application (architectural domain), a specific situation (procurement phase), and for a certain building material (wooden floor). Workflow scenarios were devised for the three disciplinary roles of the **Architect (A)**, the **BIM Administrator (BA)**, and the **Contractor (C)**.

### Workflow Schema

Within the Lcs-BIP Project, a preliminary real-world performance of the eventual federated tool was sketched out and built up. A simplified workflow scheme of the tool is as follows:

- **A** submits an object-based detailed design model (BIM) in a neutral format to the data management system (Figure 1).
- **BA** checks the submitted building model for possessing all required fields | if required, additional property sets are added to the model's data structure | The building element in question (floor) is queried in the model and all instances are extracted into XML (Extensible Mark-up Language) format | An XML file is exported from S-A-s (Figures 2-4).
- **C** imports the XML file to BuildX based on a certain building element/material (in this case, the wooden floor) | Based on design requirements (e.g. desired thickness, thermal transfer/U value, life cycle greenhouse gas emissions, price, etc.), a list of commercial matches is provided | The most appropriate alternative is selected | An XML file including properties of the selected product/material is exported (Figure 5).

- BA registers the new XML file to S-A-s | A pre-check and comparison (between the design-intent model and the populated model) is performed before final registration of the new model | The environmentally optimized design model is submitted (Figure 6).

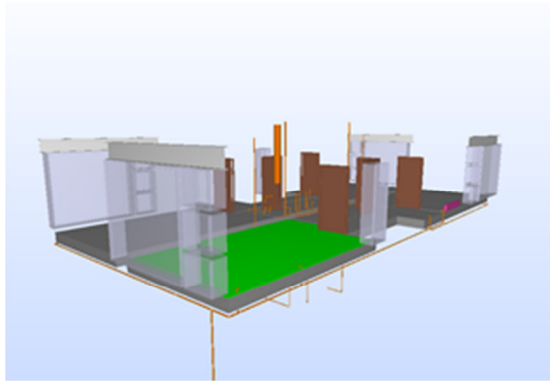
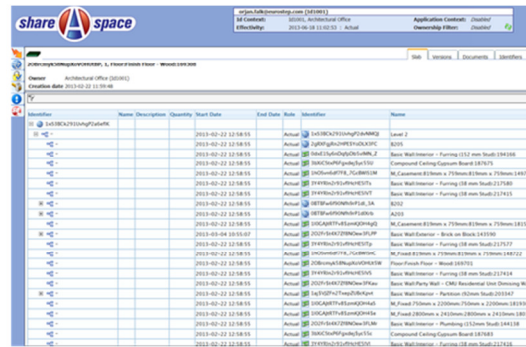


Figure 1 – A subset of the initial building model in IFC format.



Id	Name	Description	Quantity	Start Date	End Date	Rate	Manufacturer	Name
1	Level 2			2013-02-22 12:18:15			Actual	Level 2
2	Level 3			2013-02-22 12:18:15			Actual	Level 3
3	Level 4			2013-02-22 12:18:15			Actual	Level 4
4	Level 5			2013-02-22 12:18:15			Actual	Level 5
5	Level 6			2013-02-22 12:18:15			Actual	Level 6
6	Level 7			2013-02-22 12:18:15			Actual	Level 7
7	Level 8			2013-02-22 12:18:15			Actual	Level 8
8	Level 9			2013-02-22 12:18:15			Actual	Level 9
9	Level 10			2013-02-22 12:18:15			Actual	Level 10
10	Level 11			2013-02-22 12:18:15			Actual	Level 11
11	Level 12			2013-02-22 12:18:15			Actual	Level 12
12	Level 13			2013-02-22 12:18:15			Actual	Level 13
13	Level 14			2013-02-22 12:18:15			Actual	Level 14
14	Level 15			2013-02-22 12:18:15			Actual	Level 15
15	Level 16			2013-02-22 12:18:15			Actual	Level 16
16	Level 17			2013-02-22 12:18:15			Actual	Level 17
17	Level 18			2013-02-22 12:18:15			Actual	Level 18
18	Level 19			2013-02-22 12:18:15			Actual	Level 19
19	Level 20			2013-02-22 12:18:15			Actual	Level 20
20	Level 21			2013-02-22 12:18:15			Actual	Level 21
21	Level 22			2013-02-22 12:18:15			Actual	Level 22
22	Level 23			2013-02-22 12:18:15			Actual	Level 23
23	Level 24			2013-02-22 12:18:15			Actual	Level 24
24	Level 25			2013-02-22 12:18:15			Actual	Level 25
25	Level 26			2013-02-22 12:18:15			Actual	Level 26
26	Level 27			2013-02-22 12:18:15			Actual	Level 27
27	Level 28			2013-02-22 12:18:15			Actual	Level 28
28	Level 29			2013-02-22 12:18:15			Actual	Level 29
29	Level 30			2013-02-22 12:18:15			Actual	Level 30
30	Level 31			2013-02-22 12:18:15			Actual	Level 31
31	Level 32			2013-02-22 12:18:15			Actual	Level 32
32	Level 33			2013-02-22 12:18:15			Actual	Level 33
33	Level 34			2013-02-22 12:18:15			Actual	Level 34
34	Level 35			2013-02-22 12:18:15			Actual	Level 35
35	Level 36			2013-02-22 12:18:15			Actual	Level 36
36	Level 37			2013-02-22 12:18:15			Actual	Level 37
37	Level 38			2013-02-22 12:18:15			Actual	Level 38
38	Level 39			2013-02-22 12:18:15			Actual	Level 39
39	Level 40			2013-02-22 12:18:15			Actual	Level 40
40	Level 41			2013-02-22 12:18:15			Actual	Level 41
41	Level 42			2013-02-22 12:18:15			Actual	Level 42
42	Level 43			2013-02-22 12:18:15			Actual	Level 43
43	Level 44			2013-02-22 12:18:15			Actual	Level 44
44	Level 45			2013-02-22 12:18:15			Actual	Level 45
45	Level 46			2013-02-22 12:18:15			Actual	Level 46
46	Level 47			2013-02-22 12:18:15			Actual	Level 47
47	Level 48			2013-02-22 12:18:15			Actual	Level 48
48	Level 49			2013-02-22 12:18:15			Actual	Level 49
49	Level 50			2013-02-22 12:18:15			Actual	Level 50
50	Level 51			2013-02-22 12:18:15			Actual	Level 51
51	Level 52			2013-02-22 12:18:15			Actual	Level 52
52	Level 53			2013-02-22 12:18:15			Actual	Level 53
53	Level 54			2013-02-22 12:18:15			Actual	Level 54
54	Level 55			2013-02-22 12:18:15			Actual	Level 55
55	Level 56			2013-02-22 12:18:15			Actual	Level 56
56	Level 57			2013-02-22 12:18:15			Actual	Level 57
57	Level 58			2013-02-22 12:18:15			Actual	Level 58
58	Level 59			2013-02-22 12:18:15			Actual	Level 59
59	Level 60			2013-02-22 12:18:15			Actual	Level 60
60	Level 61			2013-02-22 12:18:15			Actual	Level 61
61	Level 62			2013-02-22 12:18:15			Actual	Level 62
62	Level 63			2013-02-22 12:18:15			Actual	Level 63
63	Level 64			2013-02-22 12:18:15			Actual	Level 64
64	Level 65			2013-02-22 12:18:15			Actual	Level 65
65	Level 66			2013-02-22 12:18:15			Actual	Level 66
66	Level 67			2013-02-22 12:18:15			Actual	Level 67
67	Level 68			2013-02-22 12:18:15			Actual	Level 68
68	Level 69			2013-02-22 12:18:15			Actual	Level 69
69	Level 70			2013-02-22 12:18:15			Actual	Level 70
70	Level 71			2013-02-22 12:18:15			Actual	Level 71
71	Level 72			2013-02-22 12:18:15			Actual	Level 72
72	Level 73			2013-02-22 12:18:15			Actual	Level 73
73	Level 74			2013-02-22 12:18:15			Actual	Level 74
74	Level 75			2013-02-22 12:18:15			Actual	Level 75
75	Level 76			2013-02-22 12:18:15			Actual	Level 76
76	Level 77			2013-02-22 12:18:15			Actual	Level 77
77	Level 78			2013-02-22 12:18:15			Actual	Level 78
78	Level 79			2013-02-22 12:18:15			Actual	Level 79
79	Level 80			2013-02-22 12:18:15			Actual	Level 80
80	Level 81			2013-02-22 12:18:15			Actual	Level 81
81	Level 82			2013-02-22 12:18:15			Actual	Level 82
82	Level 83			2013-02-22 12:18:15			Actual	Level 83
83	Level 84			2013-02-22 12:18:15			Actual	Level 84
84	Level 85			2013-02-22 12:18:15			Actual	Level 85
85	Level 86			2013-02-22 12:18:15			Actual	Level 86
86	Level 87			2013-02-22 12:18:15			Actual	Level 87
87	Level 88			2013-02-22 12:18:15			Actual	Level 88
88	Level 89			2013-02-22 12:18:15			Actual	Level 89
89	Level 90			2013-02-22 12:18:15			Actual	Level 90
90	Level 91			2013-02-22 12:18:15			Actual	Level 91
91	Level 92			2013-02-22 12:18:15			Actual	Level 92
92	Level 93			2013-02-22 12:18:15			Actual	Level 93
93	Level 94			2013-02-22 12:18:15			Actual	Level 94
94	Level 95			2013-02-22 12:18:15			Actual	Level 95
95	Level 96			2013-02-22 12:18:15			Actual	Level 96
96	Level 97			2013-02-22 12:18:15			Actual	Level 97
97	Level 98			2013-02-22 12:18:15			Actual	Level 98
98	Level 99			2013-02-22 12:18:15			Actual	Level 99
99	Level 100			2013-02-22 12:18:15			Actual	Level 100

Figure 2- Building information imported to and re-structured in BIM Collaboration Hub.

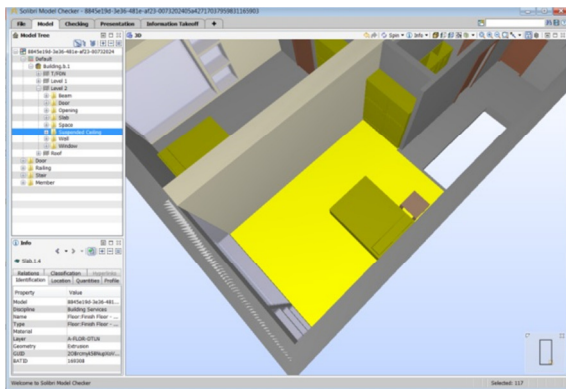
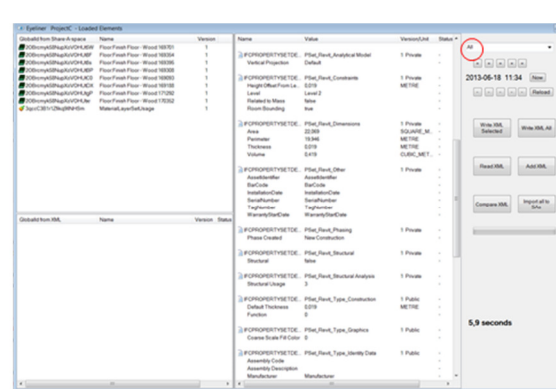


Figure 3 - The queried floor is found and displayed in the interactive view (Solibri Model Viewer).



Name	Value	Version	Status
1	1	1	1
2	1	1	1
3	1	1	1
4	1	1	1
5	1	1	1
6	1	1	1
7	1	1	1
8	1	1	1
9	1	1	1
10	1	1	1
11	1	1	1
12	1	1	1
13	1	1	1
14	1	1	1
15	1	1	1
16	1	1	1
17	1	1	1
18	1	1	1
19	1	1	1
20	1	1	1
21	1	1	1
22	1	1	1
23	1	1	1
24	1	1	1
25	1	1	1
26	1	1	1
27	1	1	1
28	1	1	1
29	1	1	1
30	1	1	1
31	1	1	1
32	1	1	1
33	1	1	1
34	1	1	1
35	1	1	1
36	1	1	1
37	1	1	1
38	1	1	1
39	1	1	1
40	1	1	1
41	1	1	1
42	1	1	1
43	1	1	1
44	1	1	1
45	1	1	1
46	1	1	1
47	1	1	1
48	1	1	1
49	1	1	1
50	1	1	1
51	1	1	1
52	1	1	1
53	1	1	1
54	1	1	1
55	1	1	1
56	1	1	1
57	1	1	1
58	1	1	1
59	1	1	1
60	1	1	1
61	1	1	1
62	1	1	1
63	1	1	1
64	1	1	1
65	1	1	1
66	1	1	1
67	1	1	1
68	1	1	1
69	1	1	1
70	1	1	1
71	1	1	1
72	1	1	1
73	1	1	1
74	1	1	1
75	1	1	1
76	1	1	1
77	1	1	1
78	1	1	1
79	1	1	1
80	1	1	1

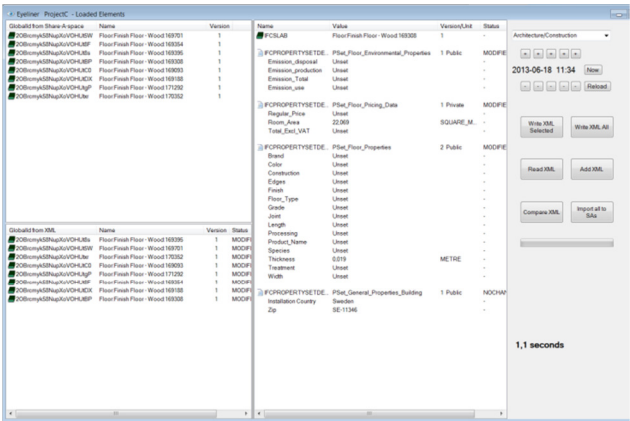


Figure 6 – The updated XML from BuildX is read and compared with the information within the Hub.

The detailed procedure for selection of the most appropriate choice of building product by the contractor will be primarily determined by the mission and objectives of the firm. Alternatively, a corporation-specific multi-criteria analysis could be applied to the items suggested by the federated tool. The eventual integration of the EPD-estimator developed within this project would enable the actors to take sustainability indicators into consideration alongside with other measures such as quality and price. Figure 7 depicts an exemplar comparative LCA report of a number of floor products created by the EPD-estimator.

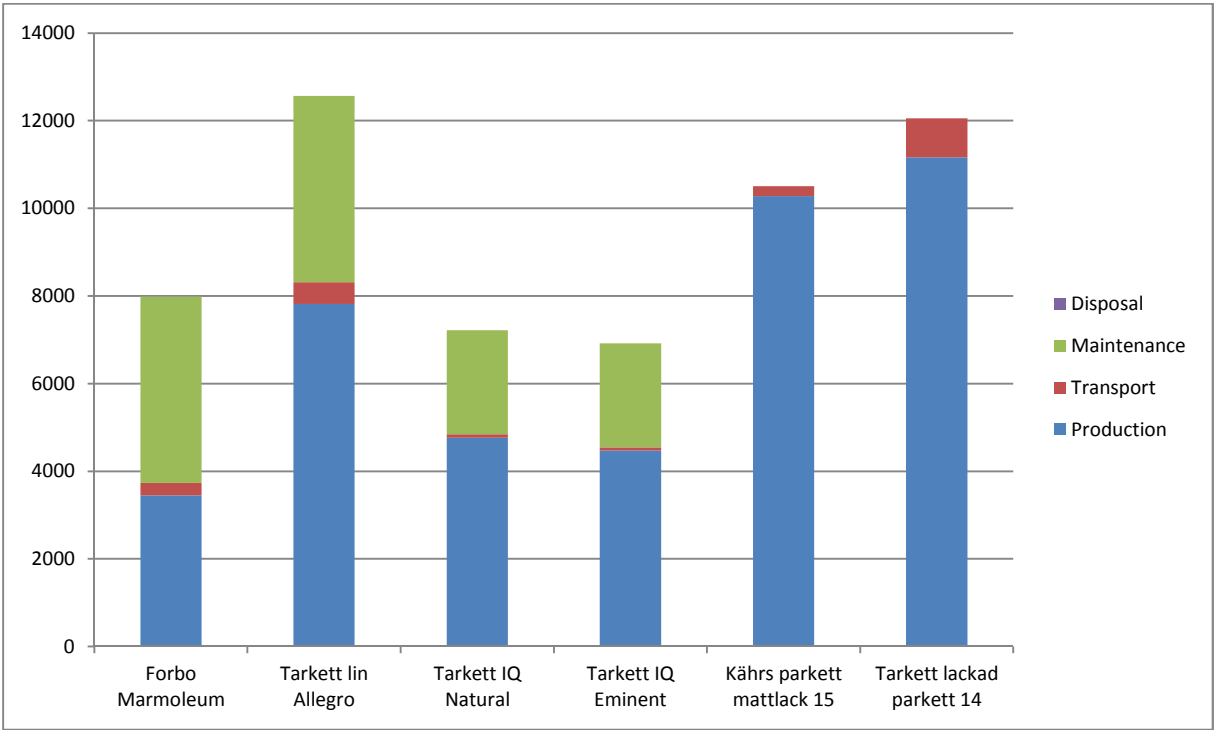


Figure 7 - An exemplar comparative LCA report of a number of floor products created by the EPD-estimator.

## Discussion

In this example, the third version of the IFC model (IFCx3) was implemented. In the latest version of IFC (IFC4), however, there are two additional property sets specific to





environmental analysis: “Pset\_EnvironmentalImpactIndicators” which represent environmental impact indicators that are related to a given “functional unit”; and “Pset\_EnvironmentalImpact-Values” that captures the environmental impact values of a specific element within a design-intent model. These two property sets directly correspond to the environmental indicators of sustainable building. Therefore, it may be plausibly claimed that the IFC model already contains the majority of the placeholders required for sustainability analysis of building products and materials e.g. energy consumption, water consumption and waste analysis [11]. Parallel initiatives by several national and international organizations are under development for eliminating the interoperability issues still prevailing. Information Delivery Manuals (IDMs), buildingSMART’s Data Dictionaries (bsDD), Model View Definitions (MVDs) [12] and BVD4 [13] are some examples.

The long-term vision of the participants in the project is to integrate Share-A-space and BuildX and make it possible to implement that integrated platform in a loosely-coupled setting together with the design and modelling tool. The intermediate import and export acts introduced in this paper will thus be cut off through software integration. This will result in a more smooth and user-friendly procedure. Thereafter, the outcome will be developed further to also include other phases, disciplinary domains and materials. To enable environmental assessment of design alternatives, the current simplified carbon footprint tool needs to be developed further, for instance to cover more products and additional environmental impact categories.

## Conclusions

BIM technologies offer promising prospects for improved sustainability approaches in design and construction. However, problems with interoperability hinder early implementation of sustainability analyses or impede reporting the results of the analyses back into design applications.

The federated solution introduced here for environmental evaluation of design alternatives is composed of a web-based tool for life-cycle-support building procurement (BuildX), coupled with a BIM-enabled platform and data sharing hub (Share-A-space). The system assists users to maintain a trifold focus on competitive price, quality, and environmental performance of the final product. The overall workflow of the system is explained through an exemplar scenario with the three disciplinary roles of an architect, a BIM administrator and a contractor. Building information is exchanged among different components of the system through a number of compatible formats, namely, IFC and XML. The eventual decision on choice of building products and materials in real-world cases will, however, be influenced by the way corporations would prioritize different measures.

The pre-assumption for this study is the downstream availability of environmental specifications of building products and materials in standard formats. Several international initiatives are in progress to realise this. The long-term vision of the participants in the project



is to integrate Share-A-space and BuildX and make it possible to implement that integrated platform in a loosely-coupled setting together with the design and modelling tools.

## References

1. Howard, R., & Björk, B.-C. (2008). Building information modelling – Experts’ views on standardisation and industry deployment. *Network methods in engineering*, 22(2), 271–280. doi:10.1016/j.aei.2007.03.001
2. Fies, B. (2011). *Deliverable 3.3: Needs, levels and potentials of integrating SB assessment and benchmarking with BIMs*. Retrieved from [http://cic.vtt.fi/superbuildings/sites/default/files/D3.3\\_0.pdf](http://cic.vtt.fi/superbuildings/sites/default/files/D3.3_0.pdf)
3. Eastman, C. M., Teicholz, P., Sacks, R., & Liston, K. (Eds.). (2011). *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*. New Jersey: Wiley.
4. Bernstein, H. M. (2012). *The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007-2012)*. McGraw Hill Construction. Retrieved from <http://bimforum.org/wp-content/uploads/2012/12/MHC-Business-Value-of-BIM-in-North-America-2007-2012-SMR.pdf>
5. Bernstein, H. M. (2010). *The Business Value of BIM in Europe*. McGraw Hill Construction.
6. SA. (n.d.). Sveriges Arkitekter - Fakta BIM. Retrieved February 5, 2014, from <http://www.arkitekt.se/s79953>
7. buildingSMART. (n.d.). Industry Foundation Classes (IFC) — buildingSMART. Retrieved October 31, 2013, from <http://www.buildingsmart.org/standards/ifc>
8. Malmqvist, T., Glaumann, M., Scarpellini, S., Zabalza, I., Aranda, A., Llera, E., & Diaz, S. (2011). Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. *Energy*, 36(4), 1900–1907.
9. EPD. (n.d.). EPD, the green yardstick. Retrieved May 15, 2014, from <http://www.environdec.com/>
10. Tarandi, V. (2012). The BIM collaboration hub supporting IDDS. In *eWork and eBusiness in Architecture, Engineering and Construction* (Vols. 1-0, pp. 819–824). CRC Press. Retrieved from <http://dx.doi.org/10.1201/b12516-130>
11. Fies, B. (2012). *Deliverable 6.3 - Recommendations for the integration of sustainable building assessment and benchmarking methods with BIMs*. Retrieved from [http://cic.vtt.fi/superbuildings/sites/default/files/D6.3\\_0.pdf](http://cic.vtt.fi/superbuildings/sites/default/files/D6.3_0.pdf)
12. buildingSMART. (n.d.). Information Delivery Manual (IDM) — buildingSMART. Retrieved February 20, 2014, from <http://www.buildingsmart.org/standards/idm>
13. IVL. (n.d.). Byggvarudeklaration, BVD4 - IVL Svenska Miljöinstitutet. Retrieved May 20, 2014, from <http://www.ivl.se/publikationer/publikationer/gemensamtdataskommunikationsformatforlivscykelinformationbyggvarudeklarationbvd4.5.3175b46c133e617730d80009750.html>

## Search for the environmental indicators relevant for the building sector

Allacker K.<sup>1</sup>, Sié M.<sup>2</sup>, Trigaux D.<sup>1</sup>, Payet J.<sup>2</sup>, De Troyer F.<sup>1</sup>

<sup>1</sup> Katholic University of Leuven, Leuven, Belgium

<sup>2</sup> CYCLECO, Ambérieu-en-Bugey, France

**Abstract:** *Life cycle assessment (LCA) is an internationally recognised methodology to calculate the environmental impact of goods and services. It is widely used to estimate the environmental impact of building products. Despite the general acceptance of the life cycle approach and the methodological steps (i.e. goal and scope definition, inventory, impact assessment, evaluation and interpretation), there is still a lot of debate on specific methodological issues. This paper focuses on one important challenge, namely the choice of environmental impact categories and corresponding indicators to be considered for the assessment of buildings and building products. More specifically, this paper discusses the balance to be found between assessment efficiency and comprehensiveness. Based on the experience in several LCA studies of buildings and building related products in the Belgian and French context, the identified relevant indicators are presented and discussed. The lessons learned are described and recommendations are formulated.*

**Keywords:** *building sector, efficiency, environmental indicators, holistic assessment*

### Introduction

Life Cycle Assessment (LCA) is a widely used approach to calculate the environmental impact of buildings and building products. This is reflected in several norms (e.g. EN15804 (1) and EN15978 (2)), guidelines (e.g. EeB Guide (3)) and simulation tools (e.g. GreenCalc (4), e-tool (5), e-LICCO (6), IES-VE (7)). Different databases moreover exist with environmental data of building products based on the LCA method (e.g. NIBE (8), OVAM-MMG (9) and EPDs (10) in general). Unfortunately these decision-supporting instruments use amongst others different system boundaries, different life cycle inventory data, different indicators, different impact assessment models and hence are not consistent. This leads to confusion and makes it difficult to interpret and to compare the environmental impacts of buildings and building related products.

This paper focuses on the selection of environmental indicators. The aim is to contribute to the ongoing discussion on relevant indicators for the building sector. The paper reports the outcome of several research projects, both in Belgium and France and compares their outcomes regarding the relevance of the environmental indicators. The assumption is that it will be easier to interpret LCA studies of buildings and building products once we have a better insight in the relevance of the different indicators. It is furthermore assumed that a more limited set of indicators would lead to less contradictory indicators and hence could avoid the need for subjective weighting. Moreover, this insight could on the longer run contribute to a

harmonisation of indicators considered in the different available standards, methods, tools and databases.

In the subsequent section the different impact assessment methods considered within the research projects are described. This is followed by an analysis of the relevance of the impact categories and a discussion of the results of the different studies. Finally, conclusions are drawn and recommendations formulated.

### **Impact assessment methods in selected research projects**

#### ***SuFiQuaD – Sustainability, Financial and Quality evaluation of Dwelling types (BE)***

In the SuFiQuaD project a methodology was developed to assess the life cycle environmental impact and financial cost of building products and buildings. The method developed was moreover applied to optimise 16 representative residential buildings from an environmental and financial perspective. Further information on this project can be found in the PhD thesis of Allacker (11) and final project report (12).

In the environmental impact assessment 17 indicators are considered, subdivided in six key-pollutants (i.e. CO<sub>2</sub>-eq., SO<sub>2</sub>, NO<sub>x</sub>, VOC, PM<sub>2.5</sub>, NH<sub>3</sub>,) and eleven impact categories (i.e. carcinogens, respiratory effects organics, respiratory effects inorganics, climate change, radiation, ozone layer depletion, ecotoxicity, acidification/ eutrophication, land use, depletion of minerals and depletion of fossile fuels). Double counting between the key pollutants and the impact categories is avoided. To calculate a single score these 17 indicators are all expressed in environmental external costs. The external costs were determined based on a combination of several methods (13), (14), (15), (16), (17). For a description of the monetary valuation in the SuFiQuaD project we refer to a publication of Allacker and De Nocker (18).

#### ***OVAM:MMG - Environmental Profile of Building elements (BE)***

The aim of the OVAM:MMG project was to develop a method to assess the environmental impact of building elements (to be extended in future to buildings) and to develop a database with the environmental profile of several building element (e.g. outer wall, inner wall, flat roof, foundation, etc.) solutions.

The environmental impact assessment in the OVAM:MMG project is an update of the SuFiQuaD method and distinguishes two sets of indicators. The first set consists of the seven EN15804 (1) indicators (i.e. climate change, ozone depletion, terrestrial acidification freshwater eutrophication, marine eutrophication, photochemical oxidant formation and metal depletion) and the second set consists of eight additional indicators based on the recommendations in the ILCD handbook (19) (i.e. human toxicity, particulate matter formation, ionising radiation (human health), terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, land occupation – forest, urban land occupation and land transformation tropical rain forest). A single score is calculated by expressing all environmental impacts in environmental external costs. For a detailed description of the OVAM:MMG project and its environmental impact assessment we refer to the project report (9).



### ***e-LICCO: evaluation tool for Low Impacts and Costs Constructions (FR)***

e-LICCO is an online software for LCA studies of buildings. It has been funded by the Bourgogne district, ADEME and the LCA consulting office Cycleco. This software relies on the C-Build e-LICCO database (ecoinvent based) (20) and the e-LICCO method for environmental impact assessment of buildings (21). Several sets of indicators can be used, among which a set of twelve recommended environmental impact indicators. The latter are elaborated further in this paper.

### ***Eco-Indicator99 (General)***

Finally, the widely used Eco-Indicator99 method was applied to several building products and buildings. For a more detailed description of this method we refer to the methodological report (22). Following environmental impact categories are considered within this method: carcinogens, respiratory effects – inorganics, respiratory effects – organics, climate change, ionising radiation – human health, ozone layer depletion, ecotoxicity, acidification/eutrophication, land use, depletion of minerals and depletion of fossil fuels.

### **Relevance of the environmental impact categories**

The results of the implementation of the SuFiQuaD method were analysed for one of the sixteen representative dwellings (detached house). Figure 1 shows the results for a selection of technical options (including both timber frame and solid structure alternatives). The relevance of the environmental impact categories in this project is determined based on the contribution (percentage) of the specific environmental impact category to the overall life cycle environmental impact (single score, expressed in monetary value). For the analysed dwelling this contribution is determined for 2714 alternatives, ranging in technical solutions and hence covering a wide range of building materials and energy performance levels. The minimum and maximum contribution of each impact category is calculated for this wide range of solutions. If at least one of the analysed building alternatives leads to a higher contribution of 10% for that specific impact category within the total single score of the building, it is assumed to be relevant. We however also identified the minimum contribution (i.e. what is the lowest contribution of that specific impact category for all building alternatives analysed). The difference between the minimum and maximum contribution of each impact category to the total score provides information on the decisive character of each indicator. It is assumed that if the difference is larger than 10%, the indicator has a decisive character.

The minimum and maximum contribution of each indicator is presented in Figure 4 based on the building life cycle results. Within this graphical representation the six key-pollutants have been integrated in the related impact categories (e.g. CO<sub>2</sub> equivalents are considered together with the impact category climate change) in order to allow for a better comparison with the results of the other methods. Following impact categories were identified as relevant based on the SuFiQuaD method: climate change, acidification, particulate matter formation and depletion of fossil fuels. Only climate change revealed to have a decisive character. A similar analysis was moreover made for a list of more than 300 building materials and products



(cradle-to-gate), in order to exclude the often dominating contribution of operational energy. The results were slightly different as following impact categories revealed to be relevant: climate change, acidification, eutrophication, particulate matter formation, respiratory effects inorganics, ecotoxicity, land use and depletion of fossil fuels. All of these were decisive indicators.

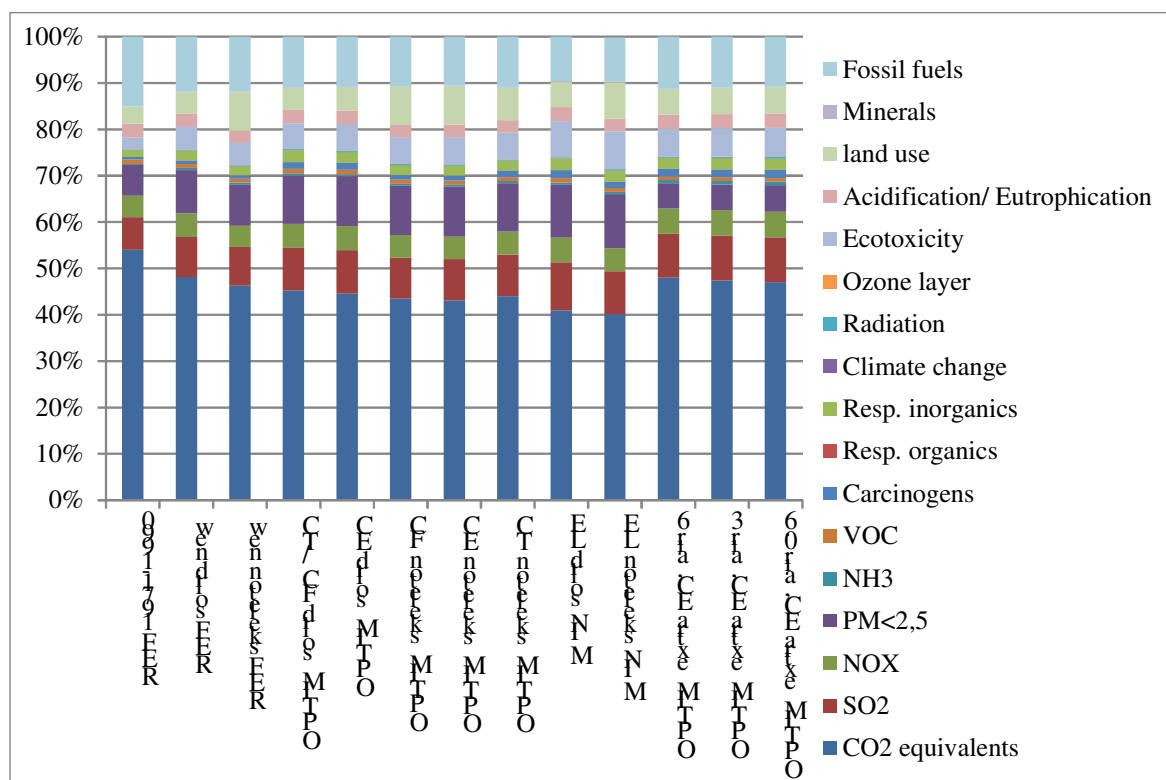


Figure 1 SuFiQuaD: environmental impact contribution analysis for several variants of a detached house, including timber frame and solid structure alternatives.

The same approach was used to determine the relevance of the impact categories considered in the OVAM-MMG method. Based on the LCA results of 25 exterior walls following environmental impact categories revealed to be relevant: climate change, freshwater eutrophication, photochemical oxidant formation, particulate matter formation and land use (i.e. land occupation – forest). This is illustrated in Figure 2 for the exterior walls. Following impact categories moreover revealed to have a decisive character: climate change, particulate matter formation and land occupation – forest. The minimum and maximum contribution of the environmental impact categories is again summarised in Figure 4 based on the LCA of the building elements. A similar analysis of the building materials (cradle-to-gate) revealed that identical impact categories were identified as relevant.

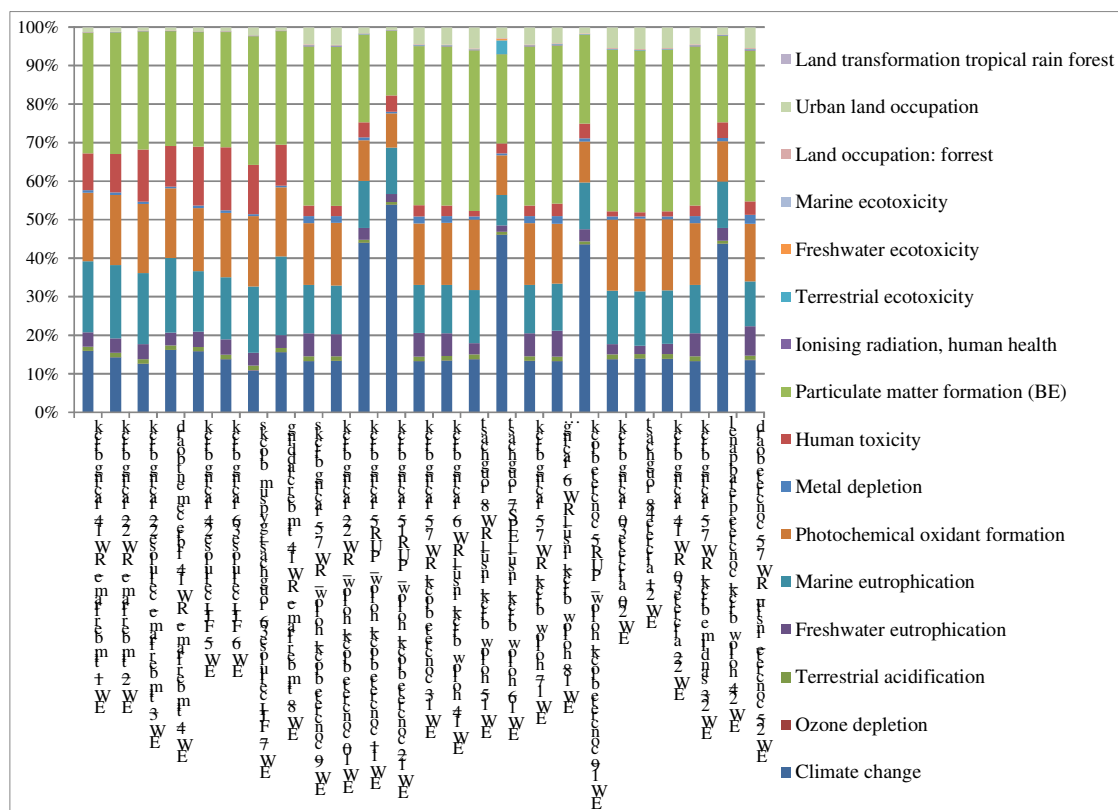


Figure 2 OVAM:MMG - environmental impact contribution analysis for several exterior wall variants including timber frame and solid structure alternatives.

The same detached dwelling which was analysed with the SuFiQuaD method was also analysed with the Eco-Indicator 99 method for a timber frame and solid structure variant. From this analysis, following impact categories were identified as relevant: carcinogens, respiratory effects inorganics, climate change and land use. The Eco-Indicator 99 method was moreover used to analyse a list of more than 300 building materials and products (cradle-to-gate). From this analysis, following environmental indicators were identified to be relevant: respiratory effects inorganics, climate change, ecotoxicity, land use, depletion of minerals and depletion of fossil fuels. The minimum and maximum contribution of each of the environmental impact for this cradle-to-gate impact is summarised in Figure 4. Because of the limited number of technical solutions analysed at the building level, the results presented in Figure 4 for Eco-Indicator 99 are those of the building product analyses. It is important to note that these hence differ from the results of the SuFiQuaD and OVAM:MMG method which are based on building LCA studies.

Within the e-LICCO project a different approach has been used to determine the relevant indicators and preferred life cycle impact assessment (LCIA) models (23). It is composed of the following steps:



Step 1: Categorisation of the midpoint environmental impacts listed in the ILCD handbook (19) and the ones provided by IMPACT 2002+ (24) and ReCiPe (25) in sub-damage categories within the three widely recognised damage categories (Ecosystem Quality, Human Health and Resources Depletion). Seven sub-damage categories have been defined: terrestrial pollution, aquatic pollution, human health, land use, materials and energetic resource depletion, water depletion and climate change. The objective of this categorisation is to group comparable indicators.

Step 2: As each sub-damage category was judged relevant, every sub-damage category needed to be covered. In consequence the sub-damage categories consisting of only one impact category were identified and the impact categories these consisted of were indicated as relevant. During this step following midpoint impacts were selected: climate change, mineral & fossil resource depletion, water depletion and land use. These are indicated in Figure 4 as full-coloured bars (no gradient).

Step 3: Based on a prior assessment of building case studies (i.e. based on energy and climate change impacts) within the e-LICCO project, a number of building related products and processes were identified as hot spots: manufacture of concrete-based products, wood-based products, metal-based products, photovoltaic panels, heating processes and French electricity mix.

Step 4: Based on the environmental assessment of the identified hot spot products/processes using the midpoint impacts of both the IMPACT 2002+ method and the ReCiPe method; the contribution (percentage) of each midpoint related to the total score of the specific sub-damage category was determined. For this analysis the damage factors of the original methods were used. Figure 3 provides an example the results of the ReCiPe midpoint impacts contributing to the human health sub-damage category.

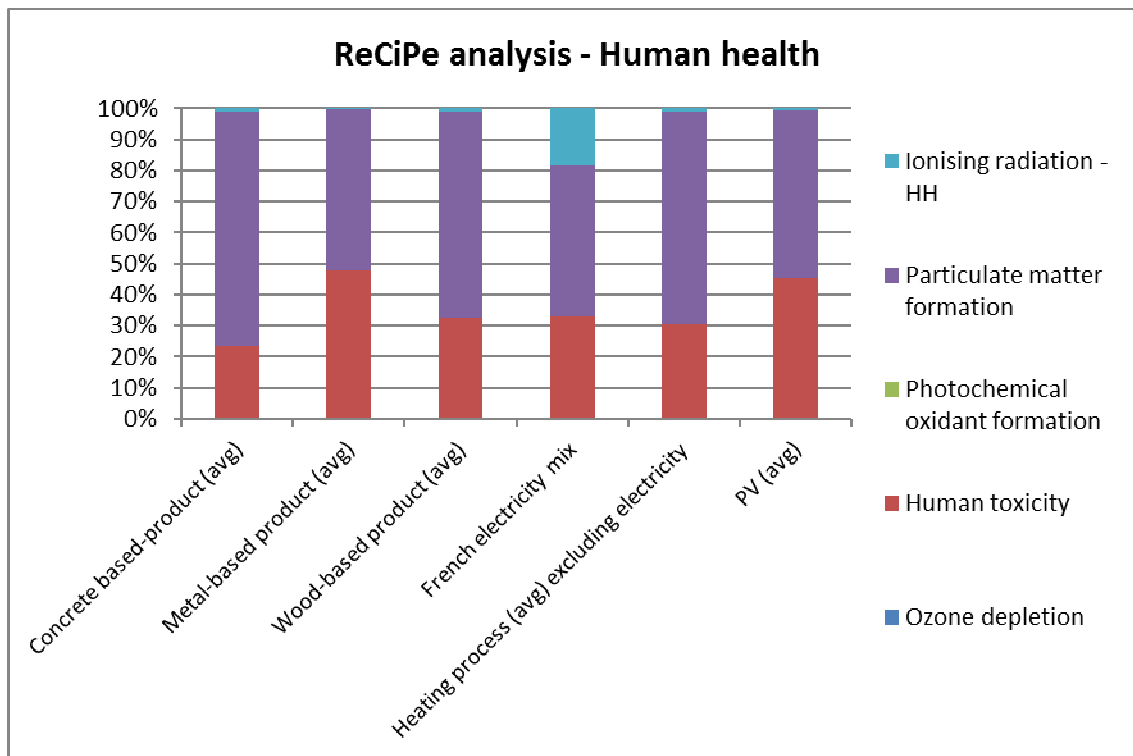


Figure 3 ReCiPe midpoint impacts contribution analysis to human health sub-damage category

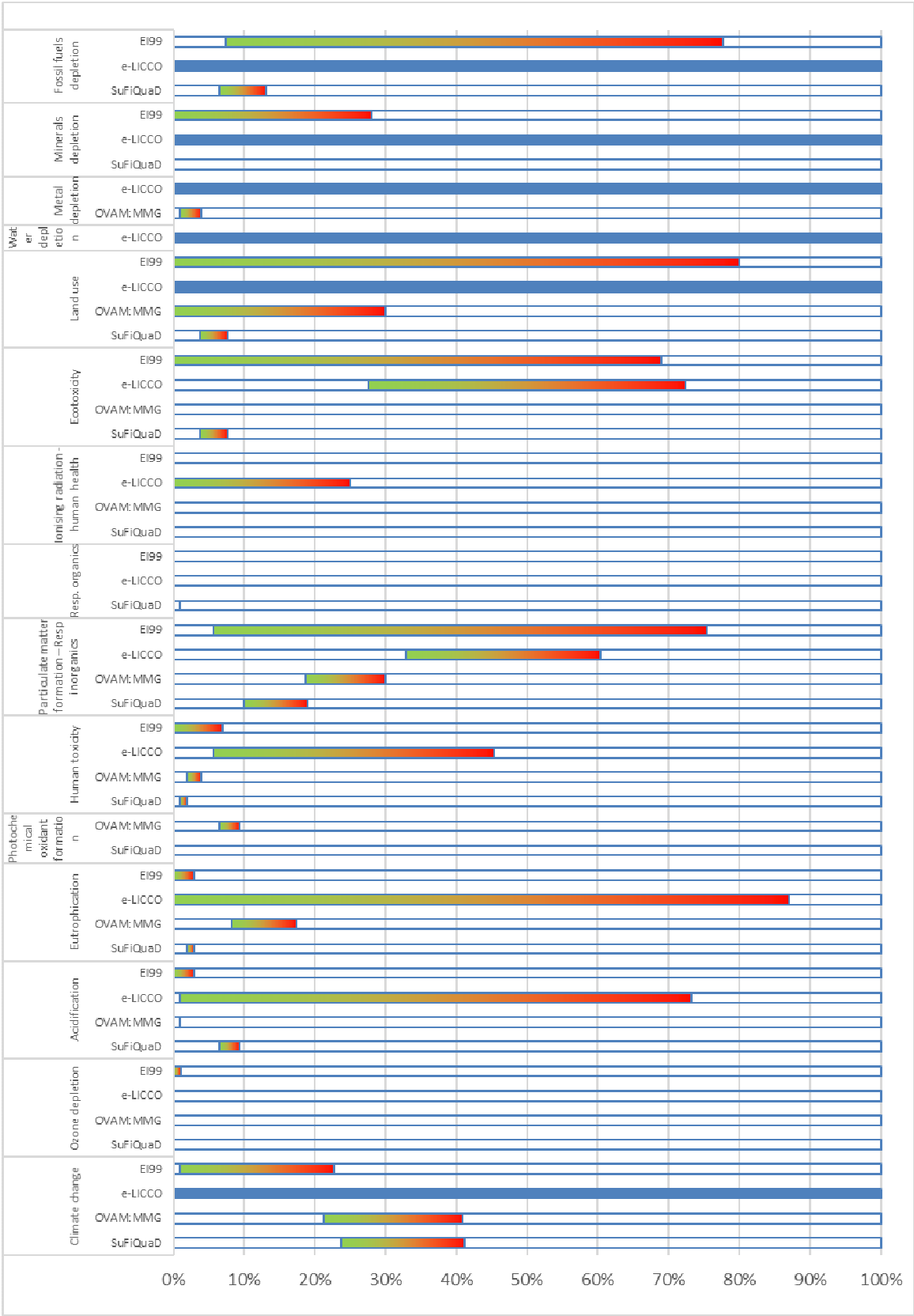
The importance of the midpoint impacts to the total sub-damage category is determined based on the contribution of the midpoint environmental impact score related to the total sub-damage score. If the contribution (C%) satisfies the following rule, the midpoint environmental impact is considered as important:

$$C\% > 1/n$$

With n the number of midpoints contributing to the sub-damage category.

Step 5: Selection of relevant indicators. The indicator is considered as relevant if it has been found important for at least one of the hot spot processes analysed

Based on this analysis, twelve environmental impact categories were identified as relevant: climate change, mineral and fossil fuel resource depletion, water depletion, terrestrial and aquatic acidification, terrestrial ecotoxicity, freshwater ecotoxicity, freshwater eutrophication, land use, ionizing radiation – human Health, respiratory inorganics, carcinogens and non-carcinogens.







*Figure 4 Contribution analysis of the different environmental impact categories according to different methods: SuFiQuaD, OVAM:MMG, e-LICCO and Eco-Indicator99. The former two are based on the LCA of buildings, while the latter two are based on the environmental assessment of several building products/processes.*

## Results

The analysis described in this paper can be seen as a first attempt to reduce the extended set of environmental impact categories to only the relevant ones for buildings and building related products. The results reveal following interesting issues. Firstly, our hypothesis that the set of indicators could be reduced by focusing only on the relevant ones proved to be correct (based on the approach suggested in this paper). We saw a reduction of the number of impact categories of about 56% for the SuFiQuaD project, 53 % for the OVAM:MMG method, 29% for the e-LICCO project and 50% using the Eco-Indicator 99 method.

However, the analysis revealed that the procedure to define the relevant impact categories has clearly an influence on the results. The use of different impact assessment methods (and hence different ways of aggregating the impact categories) leads to a different set of relevant impact categories. Moreover, the a priori assumption of relevant sub-damage categories leads to a larger set of relevant environmental impact categories than when the determination of the relevance is based on share to the total impact score (without subdivision). The latter approach however does not guarantee that all sub-damage categories are identified as relevant.

The analytical results at the building level moreover differ from the ones at the building product/process level: different sets of relevant environmental impact categories are identified. The building scale analyses lead to lower contribution ranges of all impact categories other than climate change and particulate matter, due to the large share of the latter to the total environmental impact of the building. The set of relevant impact categories at the building scale (ranging from four to five relevant impact categories) is less extended than the set of relevant impact categories at the building product scale (ranging from six to twelve relevant impact categories). Because of the transition towards nearly zero energy buildings and the drastic reduction in operational energy, the set of relevant indicators based on building materials/products seems more relevant for new buildings. For existing buildings, the relevant impact categories determined based on the building scale analysis can however be seen as a priority.

Despite the differences noticed, three impact categories are identified as relevant based on all impact assessment methods used and based on analyses at both the building level and building product level: climate change, particulate matter formation and depletion of fossil fuels.

## Conclusions and recommendations

The contribution analysis as presented in this paper provides insight in the importance/relevance of the different impact categories and hence contributes in interpreting the results of LCA studies of buildings and building related products.

That being said, there are many more approaches possible to determine the relevance of impact categories or to reduce the broad set of impact categories. The reduced set of indicators exposed in this article is still quite extended and hence weighting is still required in comparative analyses as contradictory indicators can still occur. We hence recommend to further investigate this issue in the coming future by confronting more LCA studies using different impact assessment methods and by using different techniques to determine the relevance.

### Acknowledgements

As this paper relates to several research projects, we would like to acknowledge several people. Special thanks go to the Belgian Science Policy (BELSPO), Science for a Sustainable Development (SSD), which financed the SuFiQuaD project. The OVAM is acknowledged for the financial support of the OVAM:MMG project. The colleagues from the Flemish Institute of Technological Research (VITO) and the Belgian Building Research Institute (BBRI) who were involved in both the SuFiQuaD and OVAM:MMG project are furthermore deeply acknowledged. In France, we would like to thank the Bourgogne district and ADEME for their involvement in e-LICCO project.

### References

- (1) EN:15804 (2012). *Sustainability of construction works - Environmental product declarations - Communication format business-to-business*. European Committee for Standardisation.
- (2) EN:15978 (2011). *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method*. European Committee for Standardisation.
- (3) Wittstock, B., Gantner, J., Lenz, K., Saunders, T., Anderson, J., Carter, C., Gyetvai, Z., Kreissig, J., Braune, A., Lasvaux, S., Bosdevigie, B., Bazzana, M., Schiopu, N., Jayr, E., Nibel, S., Chevalier, J., Hans, J., Fullana-i-Palmer, P., Gazulla, C., Mundy, J.A., Barrow-Williams, T., Sjöström, C. (2011). *EeBGuide Guidance Document Part B: Buildings – Operational guidance for life cycle assessment studies of the Energy-Efficient Buildings Initiative*. [www.eebguide.eu](http://www.eebguide.eu)
- (4) GreenCalc, accessed July 10, 2013, [www.greencalc.com](http://www.greencalc.com)
- (5) <http://etool.net.au/software/>
- (6) e-LICCO project, <http://e-licco.cycleco.eu>
- (7) IES-VE: <http://www.iesve.com/>
- (8) NIBE (Nederlands Instituut voor Bouwbiologie en ecologie – [Dutch Institute for Building biology and ecology] - *Milieuclassificaties Bouwproducten [Environmental Classification of Building products]*. [www.nibe.org](http://www.nibe.org)
- (9) Allacker, K., Debacker, W., Delem, L., De Nocker, L., De Troyer, F., Janssen, A., Peeters, K., Servaes, R., Spirinckx, C., Van Dessel, J. (2013). *Environmental Profile of Building elements*. Danny Wille, OVAM, Mechelen. [http://ovam.be/sites/default/files/FILE1368696514672Environmental\\_profile\\_buildig\\_elements\\_LR.pdf](http://ovam.be/sites/default/files/FILE1368696514672Environmental_profile_buildig_elements_LR.pdf)
- (10) Environmental Product Declarations. [www.environded.com/en/What-is-an-EPD/](http://www.environded.com/en/What-is-an-EPD/)
- (11) Allacker, K. (2010). *Sustainable Building: The development of an evaluation method*. PhD dissertation, KU Leuven, September 2010, ISBN 978-94-6018-231-0.
- (12) Allacker, K., De Troyer, F., Trigaux, D., Geerken, T., Debacker, W., Spirinckx, C., Van Dessel, J., Janssen, A., Delem, L., Putzeys, K. (2011). *Sustainability, Financial and Quality evaluation of*

- Dwelling Types “SUFQUAD”*. Final Report. Brussels: Belgian Science Policy (Research Programme Science for a Sustainable Development). (D/2011/1191/26)  
[www.belspo.be/belspo/SSD/science/Reports/SuFiQuaD\\_FinalReport\\_ML.pdf](http://www.belspo.be/belspo/SSD/science/Reports/SuFiQuaD_FinalReport_ML.pdf)
- (13) Holland, M., S. Pye, P. Watkiss, B. Droste-Franke, and P. Bickel. (2005). *Damages per tonne emission of PM<sub>2.5</sub>, NH<sub>3</sub>, SO<sub>2</sub>, NO<sub>x</sub> and VOCs from each EU25 member state (excluding Cyprus) and surrounding seas*. Didcon, Oxon, UK: AEA Technology Environment
  - (14) Davidson, M.D., Hof, A.F., Potjer, B. (2002). *Update Schaduwprijzen. Financiële waardering van milieu-emissies op basis van Nederlandse overheidsdoelen [Update of shadow prices. Monetary valuation of environmental emissions based on Dutch government targets]*. Delft, The Netherlands: CE Delft.
  - (15) Torfs, R., De Nocker, L., Schrooten, L., Aernouts, K. Liekens, I. (2005). *Internalisering van externe kosten voor de productie en de verdeling van elektriciteit in Vlaanderen [Internalization of the external costs for the production and distribution of electricity in Flanders]*. Mechelen, Belgium: MIRA.
  - (16) Ott, W., Baur, M., Kaufmann, Y., Frischknecht, R., Steiner, R. (2006). *NEEDS (New Energy Externalities Developments for Sustainability) - Assessment of biodiversity losses*. Zurich, Switzerland: Ecoconcept AG.
  - (17) European Commission. (2006). *World energy technology outlook 2050 (WETO-H2)*. Luxembourg: European Communities.
  - (18) Allacker, K., De Nocker, L. (2012). Approach for calculating the environmental external costs of the Belgian building sector. *Journal of Industrial Ecology*, 16(5): 710-721.
  - (19) European Commission, Joint Research Center, Institute for Environment and Sustainability. (2012). *Characterisation factors for the ILCD recommended Life Cycle Impact Assessment method*. EUR 25167 EN.
  - (20) Sié, M., Lautridou, P., Payet, J., Marie, D., Combet, L. (2013). Development of an inventory database of materials products and equipments for the french construction sector. *Proceedings of the [avniR] Conference 2013*, Lille.
  - (21) Sié, M., Payet, J. (2014a). *Procédure de sélection des indicateurs d'impacts recommandés pour l'analyse et l'interprétation*. Available from July 2014 on <http://e-licco.eu>
  - (22) Goedkoop, M., Spriensma, R. (2001). *The Eco-Indicator 99 A damage oriented method for Life Cycle Impact Assessment - Methodology Report*. Amersfoort, The Netherlands: Pré Consultants B.V.
  - (23) Sié, M., Payet, J. (2014b). *Méthodologie d'évaluation environnementale du bâtiment – e-LICCO*. Available from July 2014 on <http://e-licco.eu>
  - (24) Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., Rebitzer, G., Rosenbaum, R. (2003). IMPACT 2002+: a new life cycle impact assessment methodology. *The International Journal of Life Cycle Assessment*, 8(6): 324-330.
  - (25) Goedkoop, M.J., Heijungs, R., Huijbregts, M., De Schryver, A.;Struijs, J., Van Zelm, R. (2009). *ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: Characterisation*, [www.lcia-recipe.net](http://www.lcia-recipe.net)

## **The Effect of a green roof on thermal comfort and learning performance in a naturally ventilated classroom in a hot and humid climate**

### **Speakers:**

Huang, Wen-Pin<sup>1</sup>; Ruey-Lung, Hwang<sup>2</sup>; Kuo-Tsang Huang<sup>3</sup>

<sup>1</sup> Feng Chia University, Taichung, Taiwan

<sup>2</sup> National United University, Miaoli, Taiwan

<sup>3</sup> National Taiwan University, Taipei, Taiwan

**Abstract:** *Green roofs have been considered as an ecological strategy for improving indoor thermal comfort levels. By analyzing the results of an experiment, this paper discusses overheating and learning performance in two naturally ventilated classrooms, one below a green roof and one below a bare roof. In this study, indoor thermal conditions were measured in order to determine the occurrence of overheating during the hot periods of the year and, as well, the severity of thermal discomfort was examined in each classroom. The overheating periods were determined over a period of time where indoor operative temperatures reached or went above the upper limits of acceptability for 3 categories according to EN 15251. Besides assessing the risk of overheating, the study also investigates the effects of green roofs on students' learning performances. The conclusions highlight the importance of green roofs for improving thermal comfort and students' learning performance in naturally ventilated classrooms in hot and humid climates.*

**Keywords:** *green roof, thermal comfort, schoolwork performance, overheating risk*

### **Introduction**

In Taiwan, elementary and high schools traditionally have been naturally ventilated. Numerous Taiwan schools in the cities have been experiencing overheating in the summer month and demands for cooling the classroom have increased. Outdoor air temperatures continue to rise as a result of global warming and urban heat island. By providing better thermal conditions in school classrooms students will have fewer complaints and, as well, they will be able to focus more on their studies. This has convinced school administrators and designers to treat the risk of overheating in the summer months as a real and serious issue, particularly for the classrooms directly below the building's roof.

Due to the intensity of strong solar radiation and long hours of direct sunlight, it is difficult for a classroom directly below a roof to maintain proper indoor thermal comfort levels during the warm and hot months of year, especially those classroom without sufficient insulation. A green roof is an ecological design method, which uses the foliage of plants to reduce heat going into the building. The vegetation layer limits heat entering the building and the solar radiation is absorbed and converted by the plant's photosynthesis, evapo-transpiration, and respiration. The equivalent albedo of a green roof is in the range of 0.7-0.85 which is much

higher than that (0.1-0.2) of a bare roof. Moreover, the layer of soil gives an added insulation to the building's roof and, as well, the water content of the soil increases thermal inertia. Green roofs are typically used in warm and hot climates to enhance the insulation performance of roofs, making the buildings less prone to overheating in the summer because of their thermal behaviour with the solar radiation.

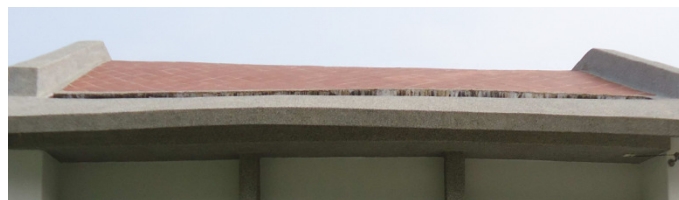
Here we presented a study that investigated the risk of overheating and the learning performance of the students in two naturally ventilated classrooms directly below a building's roof, one having a green roof and the other a bare roof. Through measurements of the microclimatic variables, this study assessed the risk of overheating and student's learning performance in two classrooms directly below both a green roof and a bare roof. The study's ultimate goal was to analyze the effects of a green roof in the naturally ventilated school buildings and how it reduces the risk of overheating while improving the learning performance of students.

### **Experiment set up, instrumentation and location**

The experiment was conducted in a naturally ventilated, two-story, southwest facing school building in Taichung, Taiwan. The experiment's measurements were taken in two classrooms directly below two different kinds roofs; a green roof and a bare roof (see figure 1). The size of each room is 9.0 m x 8.0 m. For this study, a period of climatic monitoring was conducted in both classrooms from September 7<sup>th</sup> to October the 25<sup>th</sup>, 2014, during the first six weeks of the school semester. This period was selected as it is the time of year in Taiwan when the weather gradually transitions from hot to cool.



*(a) green roof*



*(b) bare roof*

*Fig. 1 The photographs of (a) green roof and (b) bare roof investigated in this study*

The air temperature, relative humidity(RH), globe temperature, and wind speed were continuously monitored during this period. Only the measurements recorded at the time when the classroom was in session were used for the analysis. The air temperature and RH were



recorded using ESCORT iLog Temperature/Humidity Datalogger, and globe temperature using the CENTER 314. A hot-wired omni-directional DeltaOHM thermo-anemometer HD2103.2 was used to record the wind speed. All the instrumentation used are in accordance with the ISO 7726 [1] requirements on equipments for evaluating the status of thermal environment. A central spots in the classrooms were selected as points of climatic monitoring.

### Methodology for assessing risk of overheating

Current international standards for indoor thermal environment in naturally ventilated buildings are the “ASHRAE Standard 55:2010-Thermal Environmental Conditions for Human Occupancy” [2] and “European Standard EN 15251:2007-Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics” [3]. Based on the database developed in the 2000s from field surveys in naturally ventilated school buildings, when the upper limit of the comfort zones for the warm season of Taiwan projected by these two standards was compared, Hwang and Shih[4] found that the predictability of the adaptive model in ASHRAE 55 appeared to be less than that of the model in EN 15251. Thus, EN 15251 was adopted as the thermal comfort standard in this study.

In EN 15251, the optimal indoor operative temperature ( $T_c$ ) in naturally ventilated buildings is predicted as:

$$T_c = 0.33 \times T_{rm} + 18.8 \quad (1)$$

$$T_{rm} = (T_{-1} + 0.8 \times T_{-2} + 0.6 \times T_{-3} + 0.5 \times T_{-4} + 0.4 \times T_{-5} + 0.3 \times T_{-6} + 0.2 \times T_{-7}) / 3.8 \quad (2)$$

where  $T_{rm}$  is exponentially weighted running mean of the outdoor temperature;  $T_{-1}$  is daily mean outdoor temperature for the previous day;  $T_{-2}, \dots$  is daily mean outdoor temperature for the day before and so forth.

The acceptable bands for the 3 categories of buildings used in EN 15251 are:  $T_c \pm 2$ ,  $T_c \pm 3$  and  $T_c \pm 4^\circ\text{C}$  for categories I, II and III respectively.

Furthermore, the risk and magnitude of overheating can be calculated according to the amount by which the operative temperature for any given hour exceeds the predicted comfort temperature calculated using equation (1). The European Standard EN 15251 defines the likelihood of overheating as equation (3)

$$PD_H = \frac{\exp[0.4734 \times \Delta T - 2.607]}{1 + \exp[0.4734 \times \Delta T - 2.607]} \quad (3)$$

where  $PD_H$  is the proportion in heat discomfort and  $\Delta T$  is the difference between the actual operative temperature and the comfort temperature.

Operative temperature is the thermal index used throughout this study as it is the one used for the assessment of the indoor environment in EN 15251. The operative temperature is the

weighted average of the air temperature and the mean radiant temperature and expresses their combined effect. The weights depend on the convective and the radiant heat-transfer coefficients of the clothed body of the occupant. The operative temperature is calculated using Equation (4) [5].

$$T_{op} = \frac{T_a \cdot \sqrt{10v} + T_r}{1 + \sqrt{10v}} \quad (4)$$

$$T_r = [(T_g + 273)^4 + (1.2 \times 10^5 \cdot d^{-0.4})v^{0.6}(T_g - T_a)^{0.25} - 273] \quad (5)$$

where  $T_g$ ,  $T_a$  and  $v$  are the measured values of globe temperature, air temperature and air velocity, respectively. The globe's diameter  $d$  used in this study is 150mm.

### Results of Measurements

Figures 2 show the maximum, minimum and daily mean outside temperature for the monitoring periods. Also shown are the adaptive thermal comfort ( $T_c$ ) and upper limits for Category I and II.

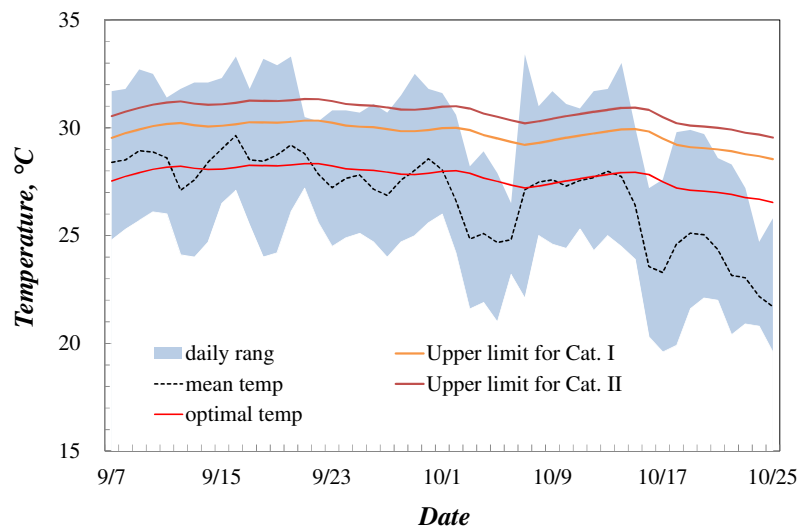


Fig. 2 Distribution of ambient temperature, optimal comfort temperature and upper limits for Category I and II in Taichung, Taiwan over the whole monitoring period (from Sept. 7<sup>th</sup> to Oct. 25<sup>th</sup>, 2013)

The measured indoor air temperatures during school hours (08:00-12:00 for Wednesday and 08:00-16:00 for other weekdays) of the classroom directly below both the green roof and bare roofs are presented in Figure 3. The measured air temperatures fluctuates between 23.5 to 32.2 °C inside both classrooms, indicating that it is sometimes too hot during sunny afternoons by referred to by the upper limits of Category II and depicted by the dashed line in Figure 3. It is also observed that the application of a green roof contributes to the reduction of the indoor temperature during most of the monitored period.

Table 1 summarises the cumulative hours where temperatures reached or went above the upper limits of category I, II and III in EN 15251. The number of hours exceeding Category I limits is reduced from 159 to 130 when a green roof is in place, while the hours exceeding Category II limit is reduced by two-third when a green roof is applied. The number of hours of temperature higher than Category III limits is 34 for bare roof compared to 10 for green roof.

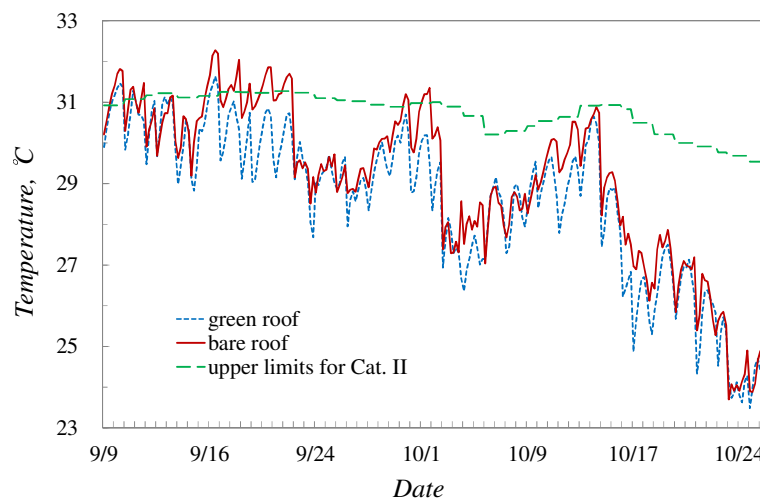


Fig. 3 Indoor operative temperature profile during school hours over the whole monitoring period

Table 1 Cumulative hours exceeding three reference temperatures

	Category I	Category II	Category III
Green roof	130 (52%)	66 (26%)	10 (4%)
Bare roof	159 (63%)	100 (40%)	34 (13%)

For each hour of occupation over the whole monitoring period, the difference between the actual operative temperature and the comfort temperature was calculated, and the proportion of human occupants not comfortable was evaluated using equation(3). Figure 4 shows a histogram of the  $PD_H$  profiles recorded for both the green roof and bare roof. The maximum  $PD_H$  was 28% in the case of the green room, compare to 34% in the case of the bare roof. Similarly, the averaged  $PD_H$  over the whole monitoring period increased from 11.6% in the case of green roof and by 14.3% in the case of bare roof.

### Impact on student's learning performance

To calculate the effects of the thermal climate on student's learning performance, the hourly measured temperatures for each classroom were substituted into an empirical equation, suggested by Seppanen et al [6], to translate indoor temperature to schoolwork performance. The formula is shown in equation (6) and applicable for an indoor air temperature range of 15-35°C. According to equation (6), maximum performance is reached at an indoor temperature of 21.8°C. The productivity is reduced by 11.7% when the indoor temperature reaches the maximum of  $T_{max}$  (31.7°C) over the whole monitoring period.

$$RP = 0.1647524 \times T_a - 0.0058274 \times T_a^2 + 0.0000623 \times T_a^3 - 0.4685328 \quad (6)$$

where RP is relative performance, and  $T_a$  is room temperature ( $^{\circ}\text{C}$ ).

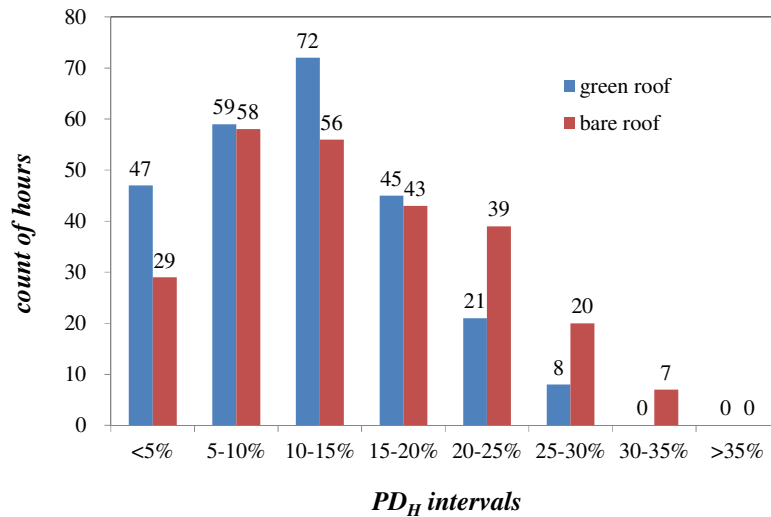


Fig. 4  $PD_H$  histogram for the whole monitoring period

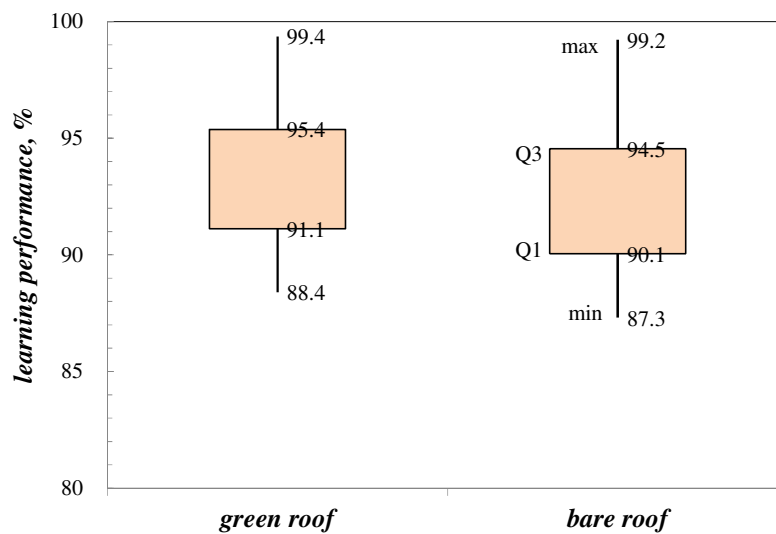


Fig. 5 Box plots for the predicted learning performance ( $Q1=25\%$  percentile,  $Q3=75\%$  percentile)

With the measured temperature profiles as input, equation(6) was used to determine hourly performance indices in both indoor and outdoor environments. Figure 5 shows the predicted students performance in the classrooms below a green roof and a bare roof. The resulting average performances were 93.3% and 92.5% for the green roof and the bare roof, respectively. The students' learning performance in the classroom with a green roof is slightly increased compared to that of the classroom with a bare roof.



## Conclusion

This study investigated the contribution of a green roof and its effects on the thermal comfort levels in the school building where it has been placed. The conclusions are summarized as follows:

The green roof reduced the occurrence of overheating. Concluded from the measured indoor operative temperatures in each classroom, lower occurrence of overheating was measured in the classroom covered by green roof and likewise there was a higher occurrence of overheating in the classroom covered by a bare roof. When a green roof was applied, the percentage of school hours where temperatures exceeding the upper limit of category II in EN 15251 was reduced from 63% to 52%, from 40% to 26% for Category II and from 13% to 4% for Category III.

As well, the green roof reduced the severity of discomfort during hot periods. The maximum  $PD_H$  in the case of green roof was 28%, compared to 34% in the case of the bare roof. Similarly, the average  $PD_H$  over the whole monitoring period increased by 11.6% in the case of green roof and by 14.3% in the case of bare roof.

Finally, the impact of a green roof on students' learning performance is slightly less than 1%.

## Acknowledgement

We offer our sincere appreciation for assistance in grant to the Ministry of Science and Technology of Taiwan under the project number NSC-102-2221-E-239-028.

## Reference

- [1] ISO(1988), ISO Standard 7726:1998, Ergonomics of the Thermal Environment—Instruments for Measuring Physical quantities. Geneva: International Standard Organization.
- [2] ASHRAE (2010), ASHRAE Standard 55:2010, Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- [3] CEN(2010), EN 15251:2007, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, Brussels: CEN.
- [4] Hwang R.L., Shih W.M. (2014), Applicability of different adaptive thermal comfort standard in Taiwan, HV&AC, 44(1):23-27.
- [5] CIBSE (2006), Guide A-Environmental design, London, Chartered Institution of Building Services Engineers.
- [6] Seppanen O., Fisk W., Lei Q. (2006), Effect of temperature on task performance in office environment. Lawrence Berkeley National Laboratory, LBNL report 60946.



## Using evolutionary optimization for low-impact solid constructions

### Authors:

Hollberg, A.<sup>1</sup>; Heidenreich, C.<sup>1,2</sup>; Ruth, J.<sup>1,2</sup>; Hartung, R.<sup>2</sup>; Herzog, S.<sup>2</sup>

<sup>1</sup> Department of Structural Design, Bauhaus-Universität Weimar, Germany

<sup>2</sup> Department of Solid Construction II, Bauhaus-Universität Weimar, Germany

### Abstract:

*This paper introduces a parametrical approach for optimizing concrete slabs based on life cycle assessment (LCA). The developed method is implemented in a graphical algorithm editor. Evolutionary solvers are used to minimize the global warming potential (GWP), which serves as a representative indicator for environmental impact. Comparing a mathematical analysis of all possible solutions with the results of the evolutionary algorithms demonstrates the efficiency of these. The application of the method is demonstrated using a bike garage as an example. The great potentials for saving GWP compared to a conventional slab design are revealed. Furthermore, this paper proves that the method makes a relevant contribution towards lowering the environmental impact of the building sector.*

***Life cycle assessment, sustainable solid construction, optimization, evolutionary algorithm, parametric design tools***

### Introduction

The building sector is responsible for a great share of the world's resource and energy consumption [1]. Solid constructions made of concrete are one of the most common ways to build in almost every country. Due to the cement, the environmental impact of concrete is high, meaning there is a necessity for optimization, but also a high potential to achieve it.

Reducing the thickness of building components and the resulting reduction in the quantity of material used is an important issue in civil engineering. One possible approach is to reduce the span of a concrete slab by intelligently arranging the vertical support elements. The second possibility is to reduce the thickness by using high-strength concrete. However, the material savings achieved by doing so have to be investigated holistically within the context of environmental effects.

### Environmental data

One method to systematically investigate environmental impact is life cycle assessment (LCA). The methodology is regulated in ISO 14040. In the building sector LCA is currently becoming more prevalent and environmental product declarations (EPD) are available for a range of typical building materials and products. In this study, we used the environmental data for concrete from EPD provided by the German Institute of Building and Environment [2]. They are based on data for a mix of ready-mix concrete and precast concrete parts. The mix is weighed according to the statistical share of both types in Germany. The declared unit is 1 m<sup>3</sup>. The environmental data is given for different stages of the product. These are defined in the Product Category Rules (PCR) in DIN EN 15804.

The different modules are shown in table 1. A1-A3 represent the cradle-to-gate phase, A4 stands for transportation to the building site and A5 for installation at the site. In the EPD it was assumed that no maintenance is needed during the use phase, resulting in zero impact in module B. C1-C3 includes the demolition, transport to the reprocessing plant and the crushing of concrete. Module C4 is not considered in the EPD. Module D represents benefits outside the system boundaries, in this case the recycling. Recycled concrete is mostly used as replacement for sand and gravel in the construction of roads.

Table 1: Global Warming Potential of different concrete classes in kg CO<sub>2</sub>-equivalent (based on [2])

Concrete class	unit	Module						A + C	Total
		A1-A3	A4	A5	B	C1-C3	D		
<b>C20/25</b>	m <sup>3</sup>	190.71	3.0	1.35	0	4.87	-23.08	199.93	<b>176.85</b>
<b>C25/30</b>	m <sup>3</sup>	211.11	3.0	1.35	0	4.87	-23.08	220.33	<b>197.25</b>
<b>C30/37</b>	m <sup>3</sup>	231.91	3.3	1.35	0	4.87	-23.08	241.43	<b>218.35</b>
<b>C35/45</b>	m <sup>3</sup>	265.11	5.5	1.35	0	4.87	-23.08	276.83	<b>253.75</b>
<b>C45/55</b>	m <sup>3</sup>	313.31	15.4	1.35	0	4.87	-23.08	334.93	<b>311.85</b>
<b>C50/60</b>	m <sup>3</sup>	334.71	14.8	1.35	0	4.87	-23.08	355.73	<b>332.65</b>

When we compare the different strength classes of concrete, slight differences in module A4 are noticeable, which are caused by the transportation distances (17 km for C20/25 and C25/C30 up to 120.5 km for C50/60). The greatest differences occur in module A1-A3. This is caused by the higher amount of cement needed for higher strength. Cement production is responsible for about 90% of global warming potential (GWP) of concrete [2].

In this paper we based our analysis on GWP. Other environmental indicators show the same behaviour when the strength class – and therefore the amount of cement – is increased (see table 2, figure 1). Furthermore, it can be seen that the GWP curve lies in between the other indicators. We took GWP as a representative indicator for environmental impact. Furthermore, we only compared the different concrete strength classes, assuming the amount of reinforcing steel stays the same. According to Zilch et. al, the reinforcing has less influence on the environmental impact than the concrete [3].

Table 2: Environmental indicators of different strength classes in comparison

Indicator	Unit / equivalent	C20/25		C25/30		C30/37		C35/45		C50/60	
		absolute	%	absolute	%	absolute	%	absolute	%	absolute	%
PET	MJ	654.75	100	717.75	110	797.75	122	960.75	147	1389.75	212
PENRT	MJ	654.75	100	717.75	110	797.75	122	960.75	147	1389.75	212
GWP	kg CO <sub>2</sub>	176.85	100	197.25	112	218.35	123	253.75	143	332.65	188
ODP	kg CFC11	5.79 E-07	100	6.02 E-07	104	6.43 E-07	111	7.06 E-07	122	8.64 E-07	149
AP	kg SO <sub>2</sub>	0.29712	100	0.32112	108	0.34832	117	0.39662	133	0.51422	173
EP	kg PO <sub>4</sub>	0.0515	100	0.0552	107	0.0596	116	0.0672	130	0.086	167
POCP	kg C <sub>2</sub> H <sub>4</sub>	0.036941	100	0.040041	108	0.043341	117	0.049141	133	0.062541	169
ADPeI	kg Sb	0.000338	100	0.000377	112	0.000417	123	0.000467	138	0.000546	162
ADPfoss	MJ	608.64	100	663.54	109	734.14	121	877.44	144	1276.14	210
Cement	M.-%	11.1	100	12.4	112	13.7	123	14.5	131	16.8	151

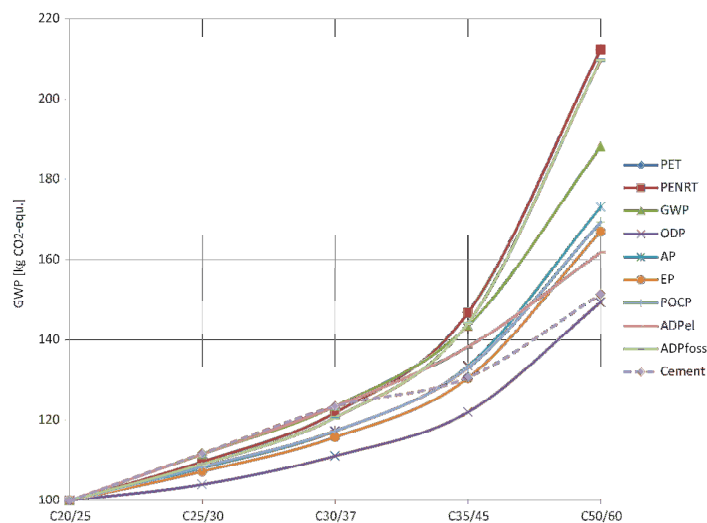


Figure 1: Normalised environmental indicators compared to C20/25 in %

### Early design stage

Decisions made in the early phases of the design process have significant consequences as they lay down general conditions for the subsequent planning process [4]. As such, they also have the biggest effect on energy demand and environmental impact [5]. Optimization based on LCA should therefore be carried out as early as possible [6]. Especially in the early design phases, when a lot of changes occur, the models for the geometry, structural analysis and LCA should ideally be adjusted easily and this requires a parametric approach. That is why we are seeing the more widespread use of graphical algorithm editors (e.g. Grasshopper3D by Robert McNeel & Associates). The finite element tool Karamba3D is fully integrated into Grasshopper3D and offers the possibility to investigate the statical behaviour, deformations and stresses for beams and shell structures in the preliminary design. Based on a parametric geometry model, a plurality of different variants can be investigated.

### The concrete slab as a functional unit

Many studies have compared different classes of concrete using LCA. The results depend a great deal on the functional unit, usually defined as  $1 \text{ m}^3$ , compressive strength in  $\text{N/mm}^2$ , or sometimes permeability [7]. For a 1m-wide strip of slab spanning 10 m we analysed five different strength classes of concrete. All of them were uniformly loaded with  $5 \text{ kN/m}^2$  and their specific deadweight. We defined the functional unit as ‘span 10 m and carry  $5 \text{ kN/m}^2$  and deadweight’.

For each concrete slab the height was varied from 10 to 30 cm in incremental steps of 1 cm. The utilization and the amount of GWP were analysed and plotted (see figure 2). In order to withstand the load, a utilization of 1.0 (which equals 100%) or lower is needed. The minimum possible slab height can be found at the point where the curve of utilization intersects with the line of utilization being equal to 1. A slab of C50/60 can be achieved with a height of only 15 cm, while 27 cm are needed for C20/25. Although almost twice the material is needed, the overall GWP is lower. The optimum could be found using C30/37 with a corresponding height of 20 cm (see table 3, figure 3).

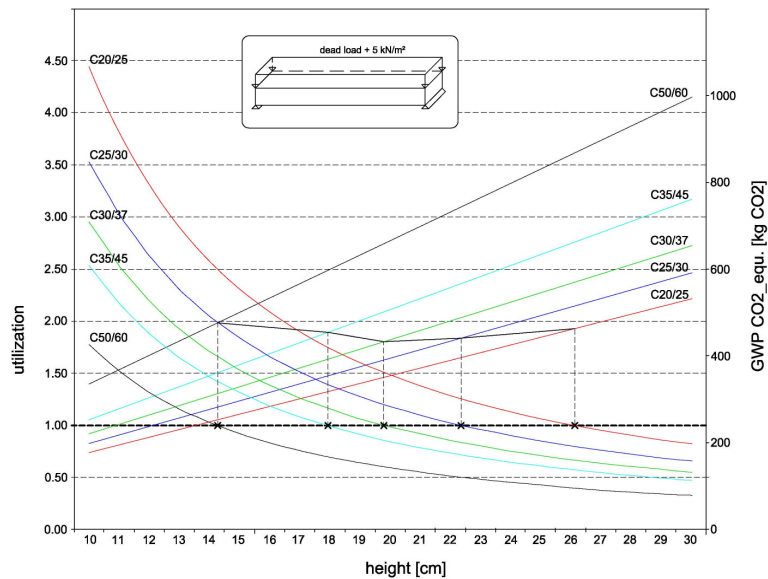


Figure 2: Utilization and GWP for different concrete classes depending on the slab height

Table 3: Minimal GWP for the slab using different concrete classes

Concrete class	Slab height	Utilization	GWP [kg]
C20/25	27 cm	95 %	477.47
C25/30	23 cm	96 %	453.68
C30/37	20 cm	98 %	436.70
C35/45	18 cm	99 %	456.73
C50/60	15 cm	92 %	498.98

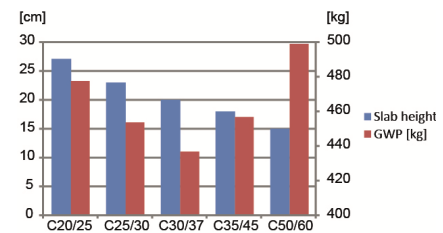


Figure 3: Slab height and GWP for a utilization of one

## Simulation and Optimization

Optimizing concrete slabs is of great interest in construction design. The complexity of the optimization problem can increase dramatically depending on the amount of variable parameters. The selection and application of appropriate optimization tools defines the required time of computation. Furthermore, the applied algorithm defines whether every possible solution will be investigated or whether there are restrictions in the search field. The slab shown in figure 4 can be optimized by two different approaches: a mathematical method and an evolutionary algorithm.

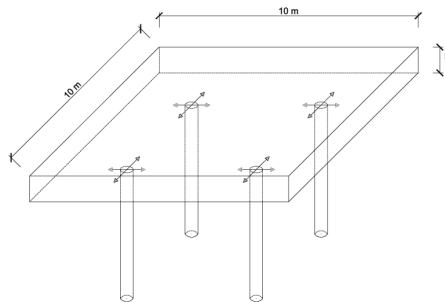


Figure 4: Point-supported slab

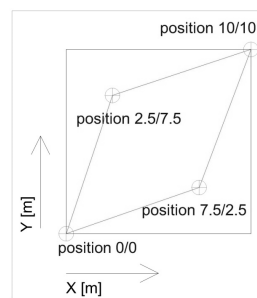


Figure 5: Mathematically evaluated support position

## Mathematical Programming

The applied method of mathematical programming is based on a parametric definition of the geometry. The positioning of the supports and the slab thickness are defined as variable parameters. In addition, the material strength can vary according to the considered types of concrete. By applying mathematical programming, all possible combinations of support positions are investigated. The combinations are generated by a self-developed tool. Afterwards, every single variant is investigated for the resulting utilization and deformation considering the different types of concrete. This is made possible by employing a loop-component. The results of the investigation are transmitted to a spreadsheet program for further evaluation and unsuitable variants, e.g. impermissible deformations, are identified and

rejected. The acceptable variants are analysed with regard to the GWP. For this purpose, the CO<sub>2</sub>-equivalent of the slab is calculated on basis of the EPDs. Finally, it is possible to determine favorable support combinations depending on the plate thickness and the concrete quality. The application of mathematical programming allows for the complete examination of the solution space. Therefore, a problem-specific description of the optimization model is required. In addition, long computation times have to be accepted.

The mathematical approach was exercised for a 10x10 m slab with four supports. With a grid size of 2.5x2.5 m there are 12,650 possible combinations of column positions. Four variants of concrete quality and four different slab thicknesses (15, 20, 25, 30 cm) were investigated resulting in a total of 202,400 variants. The solution with the lowest GWP (3.9 t) was found with the columns positioned as shown in figure 5 and with a thickness of 20 cm using C25/30. The whole analysis took 20 hours on a standard PC.

### Evolutionary Optimization

Evolutionary algorithms offer a further possibility for optimization. In civil engineering and architecture in particular, evolutionary algorithms are used when conventional algorithms cannot achieve satisfactory solutions [8]. Furthermore, they can be applied even if only little background information about the optimization problem is known [9]. These algorithms generally emulate the natural evolution with key parameters like selection, recombination and mutation.

Due to the variety of interdependent parameters, the previously considered slab (see figure 4) is evolutionarily optimized. This allows for the simultaneous consideration of the three variables: position of the columns, slab thickness and concrete quality. The evaluation of the static parameters such as deformation or utilization of the components is done in Karamba3D. Based on the defined fitness criteria (see equation 1), the evolutionary algorithm evaluates each individual solution. Optimization with the overall objective of minimizing the GWP is accompanied by secondary conditions: the limitation of deformation and utilization and the definition of a minimal distance between columns. These secondary conditions can be defined by adding special penalty criteria. The objective function itself can be defined directly in the optimizer's settings.

$$\begin{aligned} \min. GWP(x) &\in R \\ \text{with secondary condition } &\left\{ \begin{array}{l} f(x) \in [0, 1/300] \\ u(x) \in [0, 1] \\ \min. span \in [distance > 4m] \end{array} \right\} \end{aligned} \quad (1)$$

We employed an evolutionary solver called Galapagos which is integrated into Grasshopper3D. The process of optimization is displayed in figure 6. The best solution found by the solver requires a GWP of 3 t with C20/25 and a thickness of 17 cm. It also becomes apparent that normal-strength concrete (C20/25 or C25/30) is sufficient and performs better than the higher strength concrete in this investigated case.



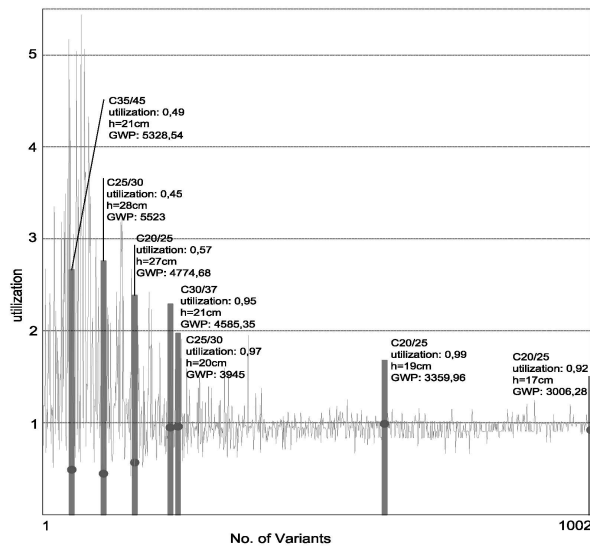


Figure 6: Evolutionary optimization of a 4-point-supported slab

### Case Study

The case study of a bike garage illustrates one of the many possible applications of the optimization method developed. The parametric geometry is based on a user-defined length and width of the slab. Here, a size of 15×30 m was chosen. The arrangement of the supports is parametrically adjusted according to the computed statical deformation behaviour. If during the repositioning process the columns are positioned closer to one another than a given limit, the algorithm automatically merges them. In this way, the amount of supports and the material needed for the columns can be kept low.

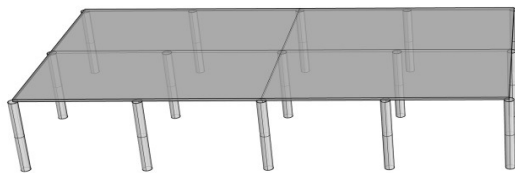


Figure 7: Standard ceiling for a bike garage

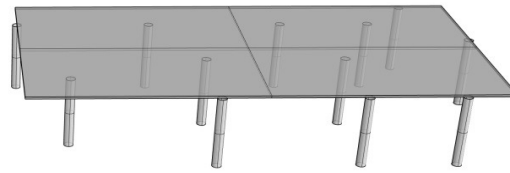


Figure 8: Optimized solution

The optimum was found using C20/25 and a slab thickness of 16 cm, with 12 supporting columns (see figure 8). This results in a GWP of 12.7 t for the whole slab. If C50/60 is used, the slab height can be reduced to 15 cm, while the emitted GWP amounts to 22.5 t. The standard solution (see figure 7) has a regular grid of 15 columns with a spacing of 7.5 m. If C20/25 is used, a thickness of 20 cm is needed, which results in a GWP of 15.9 t. Comparing the optimized and the standard solution shows that 3.2 t of CO<sub>2</sub>-equivalent can be saved. This corresponds to an improvement of 20.1%. The optimization process took 17 minutes on a standard PC.

### Conclusion

The first basic conclusion which can be drawn is the fact that solely reducing the amount of material by using high-performance material is not effective. In the presented studies here, from an ecological point of view, it was always better to choose a higher slab thickness and thus use more material of lower strength and environmental impact than to reduce the

thickness slightly by employing a high-performance concrete. It should be mentioned that the results could show a different trend when analysing other construction elements, e.g. columns. Additionally, it could be shown that the result depended to a great extent on the chosen boundary conditions and the defined functional unit. A transfer to other types of concrete or building materials requires further investigation.

The second main conclusion concerns the applied evolutionary algorithms. The algorithms proved to be efficient for the optimization especially with regard to the short computation time. On the one hand, their performance could possibly be enhanced by specific settings of the controlling parameters, such as mutation and recombination. On the other hand, their quick detection of adequate solutions without any detailed background knowledge shows their universal application. Due to this wide field of application, they are highly suited for problems in the building sector.

Optimizing concrete structures will become increasingly important in order to meet climate and environmental protection aims in the building sector. The examples given prove that the presented method makes a relevant contribution towards lowering environmental impact. The method presented here will be examined in more detail in future studies. For example, the minimum thickness of the floor slab according to the standard and the exact influence of the reinforcement could be considered. Furthermore, the impact of the columns could be integrated into the analysis.

## References

- [1] UNEP SBCI, “Buildings and Climate Change Summary for Decision-Makers,” 2009.
- [2] IBU, “Umwelt-Produktdeklaration.” [Online]. Available: <http://bau-umwelt.de/hp6239/Wozu-EPDs.htm>. [Accessed: 12-May-2014].
- [3] K. Zilch, C. Mühlbauer, A. Müller, R. Niedermeier, and A. Haas, “Verbundforschungsvorhaben ‘Nachhaltig Bauen mit Beton’ Ressourcen- und energieeffiziente, adaptive Gebäudekonzepte im Geschossbau”, DAfStb, 585, pp. 73–86, 2011.
- [4] F. Steinmann, “Modellbildung und computergestütztes Modellieren in frühen Phasen des architektonischen Entwurfs,” Bauhaus-Universität Weimar, 1997.
- [5] M. Hegger, M. Fuchs, T. Stark, and M. Zeumer, *Energie Atlas: Nachhaltige Architektur*. Birkhäuser, 2007.
- [6] A. Hollberg and J. Ruth, “Facade optimization based on life cycle demands,” in 8th Energy Forum on Advanced Building Skins., 2013.
- [7] M. Haist and H. Müller, “Nachhaltiger Beton – Betontechnologie im Spannungsfeld zwischen Ökobilanz und Leistungsfähigkeit” 9. Symposium Baustoffe und Bauwerkserhaltung, 2012, pp. 29–49.
- [8] F. Amos, K. Jung, B. Kawetzki, W. Kuhn, O. Pertler, R. Reissing, and M. Schaal, “Abschlussbericht der Projektgruppe Genetische Algorithmen” 1995.
- [9] I. Rechenberg, *Evolutionsstrategie ‘94*. fromann-holzboog, 1994.

## **Responsible management of construction resources.**

### **Amortization of the concrete's embodied environmental impact as a sustainable strategy.**

#### **Speakers:**

Vilches Such, A.<sup>1</sup>; Lizana Moral, F.J.<sup>1</sup>; Barrios Padura, Á.<sup>1</sup>; Heredia Díaz, I.<sup>2</sup>; Serrano Jiménez, A.J.<sup>1</sup>

<sup>1</sup> Higher Technical School of Architecture, Building Department, Seville, Spain

<sup>2</sup> Quality and Sustainable Development Manager, Holcim (Spain), Madrid, Spain

**Abstract:** *Cementitious derivate products are one of the most used in building sector. Despite having a low unitary environmental impact relating to other materials, its intensive use means a high impact to environment. This paper introduces the research carried out in Seville's University with the main target to evaluate strategies in order to improve and optimize the use and management of structural concrete, and analyse its environmental and service life performance. Besides locating the main energetic and emissions impacts in concrete production, it is determined the dosages with lower amortization time period (CO<sub>2</sub>e/years) regarding to its durability properties. Depending on the case of study it can get a better environmental performance using a product with a higher embodied impact but with better durable properties that will allow amortize the resource till the end of its service life.*

**Concrete, life cycle assessment, serviceability, sustainability**

#### **1. Introduction**

Reducing greenhouses gases emissions and diminishing energetic dependency of countries are world priority objectives. The Building Sector is responsible of the 30% of CO<sub>2</sub>e emissions and the 40% of primary energy consumed. Those impacts to the environment occur mainly in the life cycle stages of materials production, transport and the energy needed for building operation.

This research is focused on the analysis of CO<sub>2</sub>e emissions at the stage of materials production in order to establish efficient and sustainable design strategies.

The incessant information about the sustainability of products makes it complicated to discern which are the most reliable aspects and criteria to evaluate this concept. We should call into question the established issues and theories regarding the sustainable management of resources in Building Sector, underlining that most of the material used in construction works (ceramic, cement and aggregates), around the 80%, are not included under labelling programs neither environmental certification programs[1].

The significant concern about the reduction of the concrete environmental impact is reflected in the large amount of research projects on this topic: outlining those which propose clinker substitution by additions, the use of recycled aggregates, the optimization of heat exchange in cement plant, and the waste valorisation as alternative fuel.



All these questions are identified by the cement industry that states how the European Cement Sector is close to the limit that could be achieved due to the best available technologies and rationalization. Recent reports published by the Cement Sustainable Initiative (CSI) confirm that the current production technologies of clinker do not allow significant improvement potential regarding to energy efficiency. They highlight how Cement Sector has the possibility to reduce CO<sub>2e</sub> emissions using waste as fuel and alternative raw materials (additions and secondary raw material from ceramic industry to clinker).

### 1.1 Environmental impact of the cementitious derivative products.

Diverse research carried out with the aim of analysing concrete life cycle lead to clinker production as the main source of energy consumption and emissions to the atmosphere [2-7], estimating that regarding to the type of cement used (due to the amount of clinker), CEM I or CEM III/B, may be a variation between 60-70% of CO<sub>2e</sub> emissions.

These emissions occur because a huge amount of energy (often provided by fossil fuels) is required in clinker production. Firstly, greenhouse gases are released due to the combustion process of fuel. Secondly, calcium carbonate is decomposed at 900°C releasing significant amount of carbon dioxide, around a 59% ( $\text{CaCO}_3 + 1450^\circ\text{C} \rightarrow \text{CaO} + \text{CO}_2$ ) [4].

This is the reason why many researches propose to reduce clinker contents. However, others show that reducing it lowers its durability [8].

In this line, the present paper focuses on the evaluation and assessment of the importance of concrete durability in the definition of its environmental performance.

### 1.2 Building materials' durability as a sustainable key factor.

The principal differentiation with other researches is the inclusion of durability as essential evaluation criteria. Regarding sustainability, life service and resource optimization should be taken into account as well as the environmental aspects. This holistic approach pretends to reveal the effect of concrete damages in relation to its initial dosage and its environmental impacts associated, that will affect directly to the concrete's life service and to the environmental assessment along time.

## 2. Methodology for environmental impacts and lifetime calculations.

The methodological processes include the following three aspects: (i) quantification of environmental impact, (ii) concrete service life calculation, and (iii) correlation between variables through the structural calculation of a column.

### 2.1 Environmental impact quantification.

Nowadays, there is lack of common criteria to define the boundaries of the Life Cycle Assessment (LCA). The control of those limits is still under development to certain products through the EN 15804:2012, which establish the Category Product Rules (RCP) regulations

regarding to building materials. Because of that, and due to the high weight in the impact of the concrete that the type of conglomerate has [2-7], firstly it was made a comparative work of 21 different samples of cement in order to get representative means values of each type. The data was obtained from different Database [4,9-11] and from Environmental Product Declaration [12]. The means values used for this research are presented below:

Cement type	Energy consumption		CO <sub>2</sub> e emissions	
	Samples	[MJ / kg cem.]	Samples	[kg de CO <sub>2</sub> e / kg cem.]
CEM I	10	4,46	9	0,843
CEM II	9	3,73	8	0,742
CEM IIIa	2	3,05	2	0,420

Table 1. Average values used for each type of cement. Self elaboration.

To determinate the impact of the components (aggregates, water and additives) it was used the BEDEC Database [9], from the *Instituto Tecnológico de la Construcción*. The values used in the research are the followings:

Component	Energy consumption	CO <sub>2</sub> e emissions
	[MJ / kg]	[kg CO <sub>2</sub> e / kg]
AGGREGATE	0,150	0,00790
WATER	0,006	0,00029
ADDITIVES	93,000	13,73000

Table 2. Values used for each concrete component. Source: BEDEC database.

## 2.2 Estimation of the service life of concrete.

Concrete durability is conditioned by diverse aspects: physical, chemical, mechanical, biological and environmental [13]. Because of these limitations and due to geographical and environmental adaptation, the procedure carried out to obtain the life service of concrete was through failure process of corrosion by concrete carbonation model shown in the Annexe 9 of the Spanish structural code EHE-08 [14]. It was considered 30mm of steel covering and an environmental aggression of IIa (XC2 or XC4 according to Eurocode 2): outdoor environment without chlorides, exposed to rain with an annual precipitation higher than 600mm or foundations. The total lifetime estimated is the sum of the initial period ( $t_i$ ) and the propagation period ( $t_p$ ):

Equation	Unit	Factors:
(1)	$t_L = t_i + t_p = \left(\frac{d}{k_c}\right)^2 + \frac{80}{\phi} \frac{d}{v_{corr}}$	$t_L$ Service life (year)
		$t_i$ Initiation period by carbonation model (year)
		$t_p$ Propagation period by corrosion (year)
		$d$ Cover depth (mm)
		$K_c$ Carbonation rate
		$\phi$ Diameter of steel (mm).
		$V_{corr}$ Corrosion rate ( $\mu\text{m}/\text{year}$ ).

Table 3. Estimated service life of concrete by carbonation corrosion model. Source: Annexe 9 EHE-08.

This model does not consider the influence of water/cement ratio either the maximum amount of cement [8].



### 2.3. Calculation criteria

9 dosages of different concrete from a unique plant for C25/30, C30/37 and C35/45 were implemented, as different aggregates require different dosages of cement. As high strength category is not commonly used, for C40/50 and C45/55 were used a different plant dosages, these environmental impact results, although are slightly lower, can be used for the research having this into consideration. As well, another criteria used was to include different type of cement for every characteristic strength. This allowed us to relate all factors in a specific model: a three meters column under an axial stress.

From the structural concrete element, for each dosage it was calculated the environmental impact per cubic meter. This impact is equal to the summation of the unitary multiplied by the amount of material of every component. It was calculated the service lifetime (years) for every dosage regarding to the previous equation (Eq. 1).

### 2.4 Indicators used

To estimate the amortization along time of the concrete embodied impact kg of CO<sub>2</sub>e/year and MJ/year indicators were used. It was obtained through Eq.2.

Equation	Unit	Factors:
(2)	$I_T = \frac{A_n \cdot h \cdot i_{category}}{t_L} \quad (CO_2eq \text{ or } MJ/year)$	$I_T$ , Impact amortization factor
		$A_n$ , Resistant section area
		$h$ , Support height (3m)
		$i_{category}$ , Unitary material impact for each category: (CO <sub>2</sub> e/m <sup>3</sup> ) o (MJ/m <sup>3</sup> )
		$t_L$ , Estimated service life years of concrete

Table 4. Calculation of impact amortization factor. Self elaboration.

## 3. Results

The emissions (kg de CO<sub>2</sub>e) and embodied energy (MJ) results are showed in the following tables for each dosage. It can be deduced, from the embodied carbon results of table.5, that cement is the major component in the concrete impact with a weight around 75-85%. Aggregates and water have a lower percentage, between 3-8%, and additives represents around 10-18%. As well, dosages with CEM III/A accounted a 36,5% less emissions than CEMII/A to C25/30 concretes, and 46,1% less emissions regarding to CEM I to C30/37.

According to the table.6, CEM III/A accounted a 13,2% less embodied energy than a CEM II/A to C25/30, and a 28,4% less embodied energy than a CEM I to C30/37.

Strength Class (EN 1992) (N/mm <sup>2</sup> )	Designation according to EHE-08	Cement		Embodied Carbon (Kg CO <sub>2</sub> e)				
		Cement type	% additions	Cement	Aggregate	Water	Additives	Total kg CO <sub>2</sub> e/m <sup>3</sup>
C25/30	HA-25-B-20-IIa	CEM II/A-S 42,5 N/SRC	6-20	84,31%	4,68%	0,01%	10,99%	303,6
	HA-25-B-20-IIa	CEM III/A 42,5 N	36-65	75,26%	7,39%	0,02%	17,33%	192,5
C30/37	HA-30-F-20-IIa	CEM I 52,5 SR	0-5	81,90%	3,68%	0,01%	14,41%	380,9
	HA-30-B-20-IIa	CEM II/A-S 42,5 N/SRC	6-20	85,40%	4,35%	0,02%	10,24%	325,8
	HA-30-B-20-IIa	CEM III/A 42,5 N	36-65	76,80%	6,91%	0,02%	16,27%	205,1

C35/45	HA-35-B-20-IIa	CEM II/A-S 42,5 N/SRC	6-20	85,20%	3,57%	0,01%	11,22%	383,2
	HA-35-B-20-IIa	CEM III/A 42,5 N	36-65	76,52%	5,66%	0,02%	17,80%	241,5
C40/50	HA-40-B-20-IIa	CEM II/A-V 42,5 R	6-20	81,18%	3,78%	0,01%	15,02%	365,6
C45/55	HA-45-B-20-IIa	CEM II/A-M (P-V) 42,5 R	12-20	81,52%	3,39%	0,01%	15,08%	414,1

Table 5. Calculation result of  $K_g CO_2$  e/m<sup>3</sup> impact associated of different type of concretes. Self-elaboration.

Strength Class (EN 1992) (N/mm <sup>2</sup> )	Designation according to EHE-08	Cement		Embodied Energy (MJ)				
		Cement type	% additions	Cement	Aggregate	Water	Additives	Total MJ/m <sup>3</sup>
C25/30	HA-25-B-20-IIa	CEM II/A-S 42,5 N/SRC	6-20	72,16%	15,13%	0,05%	12,66%	1784,8
	HA-25-B-20-IIa	CEM III/A 42,5 N	36-65	67,92%	17,43%	0,06%	14,59%	1549,2
C30/37	HA-30-F-20-IIa	CEM I 52,5 SR	0-5	72,12%	11,62%	0,04%	16,22%	2291,8
	HA-30-B-20-IIa	CEM II/A-S 42,5 N/SRC	6-20	73,83%	14,19%	0,05%	11,92%	1896,0
	HA-30-B-20-IIa	CEM III/A 42,5 N	36-65	69,75%	16,41%	0,06%	13,78%	1639,9
C35/45	HA-35-B-20-IIa	CEM II/A-S 42,5 N/SRC	6-20	74,85%	11,83%	0,05%	13,27%	2194,3
	HA-35-B-20-IIa	CEM III/A 42,5 N	36-65	70,86%	13,70%	0,05%	15,38%	1893,8
C40/50	HA-40-B-20-IIa	CEM II/A-V 42,5 R	6-20	70,15%	12,33%	0,04%	17,48%	2128,6
C45/55	HA-45-B-20-IIa	CEM II/A-M (P-V) 42,5 R	12-20	71,10%	11,15%	0,04%	17,71%	2388,8

Table 6. Calculation result of MJ/m<sup>3</sup> impact associated of different type of concretes. Self-elaboration.

Depending on the different strength, the section needed for each column would be different. The most strength used the smaller section size is got; therefore the amount of material needed for the whole column would be lower. Taking into account this structural behaviour was important to analyse the results and its further discussion in conclusions.

Strength Class (EN 1992) (N/mm <sup>2</sup> )	Cement type (UNE-EN 197-1)	Geometry support		Impact of structural element			Durability	Amortization	
		Section <sup>1</sup> (cm <sup>2</sup> )	Concrete (m <sup>3</sup> )	kg CO <sub>2</sub> e/m <sup>3</sup>	Total emissions kg CO <sub>2</sub> e	% CO <sub>2</sub> e relative	Estimated service live <sup>2</sup>	CO <sub>2</sub> e/year	% CO <sub>2</sub> e/year relative
C25/30	CEM II/A-S	1220,4	0,366	303,6	111,2	100,0%	397	<b>0,280</b>	100,0%
	CEM III/A	1220,4	0,366	192,5	70,5	63,4%	317	<b>0,223</b>	79,4%
C30/37	CEM I	1017,0	0,305	380,9	116,2	104,5%	600	<b>0,194</b>	69,1%
	CEM II/A-S	1017,0	0,305	325,8	99,4	89,4%	600	<b>0,166</b>	59,1%
	CEM III/A	1017,0	0,305	205,1	62,6	56,3%	417	<b>0,150</b>	53,5%
C35/45	CEM II/A-S	871,7	0,262	383,2	100,2	90,2%	878	<b>0,114</b>	40,7%
	CEM III/A	871,7	0,262	241,5	63,2	56,8%	539	<b>0,117</b>	41,9%
C40/50	CEM II/A-V	762,8	0,229	365,6	83,7	75,3%	1246	<b>0,067</b>	24,0%
C45/55	CEM II/A-M	678,0	0,203	414,1	84,2	75,8%	1719	<b>0,049</b>	17,5%

1. Section necessary for an axial force of 3051kN, obtained for a concrete support on the ground floor of a five-storey residential building.

2. Estimated service life for a covering of 30mm and Ø12mm of diameter steel, by carbonation corrosion model.

Table 7. Amortization kg CO<sub>2</sub>e/year of a concrete structural element exposed to an environment IIa (high humidity). Self-elaboration.

Strength Class (EN 1992) (N/mm <sup>2</sup> )	Cement type (UNE-EN 197-1)	Geometry support		Impact of structural element			Durability	Amortization	
		Section <sup>1</sup> (cm <sup>2</sup> )	Concrete (m <sup>3</sup> )	MJ/m <sup>3</sup>	Total emissions MJ	% MJ relative	Estimated service live <sup>2</sup>	MJ/year	% MJ/year relative
C25/30	CEM II/A-S	1220,4	0,366	1784,8	653,4	100,0%	397	<b>1,647</b>	100,0%
	CEM III/A	1220,4	0,366	1549,2	567,2	86,8%	317	<b>1,791</b>	108,7%
C30/37	CEM I	1017,0	0,305	2291,8	699,2	107,0%	600	<b>1,166</b>	70,8%
	CEM II/A-S	1017,0	0,305	1896,0	578,5	88,5%	600	<b>0,964</b>	58,5%
	CEM III/A	1017,0	0,305	1639,9	500,3	76,6%	417	<b>1,199</b>	72,8%
C35/45	CEM II/A-S	871,7	0,262	2194,3	573,8	87,8%	878	<b>0,653</b>	39,7%
	CEM III/A	871,7	0,262	1893,8	495,3	75,8%	539	<b>0,920</b>	55,8%
C40/50	CEM II/A-V	762,8	0,229	2128,6	487,1	74,5%	1246	<b>0,391</b>	23,7%
C45/55	CEM II/A-M	678,0	0,203	2388,8	485,9	74,4%	1719	<b>0,283</b>	17,2%

1. Section necessary for an axial force of 3051kN, obtained for a concrete support on the ground floor of a five-storey residential building.



2. Estimated service life for a covering of 30mm and Ø12mm of diameter steel, by carbonation corrosion model.

Table 8. Amortization MJ/year of a concrete structural element exposed to an environment IIa (high humidity). Self-elaboration.

#### 4. Discussion

Reinforced concrete (composed of aggregates, cement, water and additions) use traditionally dosages according to the aggregate type from every cement plant. This is done with the aim of getting a certain mechanical strength, compactness and service lifetime capable to endure weather conditions on site where the building is located. The Spanish structural code (EHE-08) regulates the water/cement ratio decreasing this relation for high environmental aggressive conditions that could deteriorate concrete or rust the steel.

High proportions of cement with high levels of clinker produce high strength and compact concrete, however it has a high embodied environmental impact in terms of energy needed and CO<sub>2</sub>e emissions.

The durability studied through the EHE analysis method considered the covering of steel and the sheltering from rain as determining factors. In the current research, the used values are 30mm (d) as cover thickness and 0,5 as rain exposure factor in order to determinate the carbonation rate (kc). According to the carbonation model, a difference from 2 to 3 times more of service lifetime for rain-exposed concretes it is obtained (which are shown in the results) than for non rain-exposed concretes. Regarding the calculations, the lowest value of estimated service lifetime is 317 years (C25/30; CEM IIIa) and the higher is 1700 years for high strength concretes (C45/55; CEM II), with dosages of high level of cement. When concrete section is bearing a stress close to the maximum allowable, the lowest impact of the material is obtained with high strength concretes because of the lower amount of material needed. It is obtained in the results that for the same type of cement, a high strength concrete (C45/55) will have embodied emissions of the 75,8% regarding to a low strength concrete (C25/30). As well, the amortization of the impact of the structural element would be of a 17,5% at the end of its service life, according to the degradation model used. Therefore, the use of high strength concrete is recommendable even though they are composed of cements with higher unitary impact.

In the Building Sector, the most used calculation strengths are 25, 30 and 35 N/mm<sup>2</sup>. Within this strength the lower impact option regarding to a carbonation model is the 35N/mm<sup>2</sup> concrete using a CEM IIIa. Nevertheless, if possible using higher strength concretes would be less impacting despite the fact that the type of conglomerate is CEM II or CEM I.

However, if the column is sized due to a minimum section (the Spanish building code determinates the smallest section as 25x25cm for columns), it is better to use lower embodied carbon concrete with CEM IIIa.



## Acknowledgements

The authors acknowledge the information and support given by Herena Amaya Ruiz Fuentes, Technic Assistance and Sustainability Applications responsible of Holcim Spain. This paper has been developed from the results obtained in the framework of the Holcim Grant to Sustainable Development 2013. This grant is conceded to a recent graduate from the Higher Technical School of Architecture of the University of Seville, Spain.

## References

- [1] Barrios Padura, Á., Lizana Moral, F. J. (2013). Strategies for responsible consumption of buildings products. Proceedings of the 1st International Congress on Sustainable Construction and Eco-efficient Solutions. Seville. (pp. 243-256). ISBN: 978-84-695-7739-4.
- [2] Vold, M. and Rønning, A. (1995). *LCA of Cement and Concrete. Main report*. Stiftelsen Østfoldforskning. Fredriksstad, Norway. ISBN 82-7220-213-2.
- [3] Cardim, A. (2001). Análisis del ciclo de vida de productos derivados del cemento. Aportaciones al análisis de los inventarios del ciclo de vida del cemento. Tesis doctoral. Universidad Politécnica de Cataluña. Barcelona.
- [4] Aguado, A., Josa, A., & Cardim, A. (2004). Fortalezas y debilidades de los inventarios de cementos para su empleo en análisis de ciclo de vida (ACV). *Cerámica Y Vidrio*, 587–590.
- [5] Sjunnesson, J. (2005). *Life Cycle Assessment of Concrete*. Master thesis. Lund University. Sweden.
- [6] Roskovic, R., Radic, J., Bjegovic, D. (2010). Contribución del cemento de adición en la producción de cemento sostenible. Parte I, *Cemento hormigón*, (936): 4-10. ISSN 0008-8919.
- [7] Roskovic, R., Radic, J., Bjegovic D. (2010). Contribución del cemento de adición en la producción de cemento sostenible. Parte II, *Cemento hormigón*, (937): 38-43. ISSN 0008-8919.
- [8] Burden, D. (2006). The Durability of Concrete Containing High Levels of Fly Ash. Master Thesis, University of Brunswick
- [9] Instituto de Tecnología de la Construcción de Cataluña (ITeC), BEDEC PR/PCT.
- [10] Inventory of carbon & energy (ICE) Versión 2.0. University of BATH, Reino Unido. Enero 2011.
- [11] European Life Cycle Data (ELCD)
- [12] Declaración Ambiental de Producto (DAP) del sistema EPD international
- [13] Mendoza-Rangel, J. M. y Castro-Borges, P. (2009). Validez de los conceptos y modelos vigentes de vida de servicio de estructuras de hormigón ante los efectos del cambio climático global. Situación actual. *Materiales de Construcción*, 59(296): 117-124. doi: 10.3989/mc.2009.46608.
- [14] Instrucción del Hormigón Estructural (EHE 08). Ministerio de la Presidencia. Madrid. Anejo 9.



## Rating Resource Efficiency of Building Materials

### Speakers:

Becker, N.<sup>1</sup>

<sup>1</sup> VDI Zentrum Ressourceneffizienz GmbH, Berlin, Germany

**Abstract:** *Aiming for sustainability resource efficiency plays a major role as the building industry is one of the world's largest consumers of resources. This shows the example of Germany: its building industry is responsible for 85 % of the countries extraction of mineral raw material and produces more than 50 % of the countries waste accumulation [1]. Therefore the building sector is one of the focal points of the German Resource Efficiency Programme (ProgRes)[2]. It largely contributes to the central indicator for national resource efficiency, i. e. the raw material productivity. This is defined as the quotient of GDP in Euro and abiotic material in tons. The central aim is to double it until 2020 as compared to 1994[3].*

*Beside this very general indicator on a country wide scale it is useful to evaluate resource efficiency also on the material's level in order to improve the situation from bottom up. Based on a complete life cycle analysis a set of four indicators has been derived. These indicators have been used to analyse the resource efficiency of insulation materials and supporting structures.*

### ***Resource efficiency, life cycle analysis, insulation material, supporting structures***

#### **Introduction**

So far the discussion on sustainability has very much focused on the reduction of the building's energy consumption during use, i. e. on an increase of energy efficiency. However it is essential to also widen the view for the construction and demolition period and to gain thereby material efficiency. In the combination of energy and material efficiency resource efficiency can be achieved. To evaluate it the following set of indicators has been derived:

- type of raw material,
- embodied energy,
- greenhouse gas emission during production,
- options for disposal.

Two groups of building materials have so far been analysed with these indicators: insulation materials and supporting structures. Insulation materials are essential for the reduction of the energy consumption during the use of a building and the actual retrofitting era. The supporting structure plays a major role as it accounts for a large proportion of the weight of a building.

#### **Resource Efficiency of Insulation Materials**

The set of indicators has been applied to analyse the resource efficiency of the wide variety of insulation materials. In order to compare the different materials it has been assumed that a poorly insulated construction shall be improved to a thermal transmission coefficient of  $U =$



0.15 W/m<sup>2</sup>K. The necessary data on the embodied energy and the greenhouse gas emission has been extracted from the German database Ökobau.dat 2011 which lists nearly all in Germany available building materials [4]. Additionally, Environmental Product Declarations (EPDs) have been used [5]. The results for the most common materials can be seen in figure 1.

Insulating Material	Production Type of Raw Material	Embodied Energy, non-renewable [MJ/m <sup>2</sup> ]	Greenhouse Gas Emission [kg CO <sub>2</sub> -Eqv./m <sup>2</sup> ]	End of Life Disposal
<b>mineral</b>				
glas wool	mineral (recycling)	121,9 - 426,7	7,2 - 25,2	dump category 1/2
mineral wool	mineral	61,6 - 144,6	3,6 - 9,1	dump category 1/2
porous concrete	mineral	397,0	35,8	dump category 2
foam glass	mineral	433,5	31,0	dump category 1/2
rock wool	mineral	208,0 - 659,5	15,1 - 47,9	dump category 1/2
vacuum isolation panel	mineral (main comp.)	189,6	9,4	mat./therm. utilisation
<b>synthetic</b>				
EPS	fossil	345,3 - 497,7	11,8 - 17,3	thermal utilisation
PUR	fossil	437,9 - 517,3	22,0 - 25,1	thermal utilisation
extruded PS	fossil	642,5	28,9	thermal utilisation
<b>renewable</b>				
flax	renewable	356,1	5,7	therm. utilisation/composting
hemp	renewable	357,0	6,1	thermal utilisation
wood fibre board	renewable	223,0 - 1978,1	-63,3 - -3,9	therm. utilisation/composting
cork	renewable	280,1	-30,8	therm. utilisation/composting
cellulose fibre	renewable (recycl.)	36,9	-7,0	thermal utilisation
cellulose fibre board	renewable (recycl.)	528,3	12,3	thermal utilisation

Figure 1: Comparison of Resource Efficiency of Insulation Materials

To evaluate the results a large resource depletion has been marked in red, a medium in yellow and a low in green. For a number of materials a range of values is given for the embodied energy and the greenhouse gas emission. They have their origin in different applications of the insulation material: for example glas wool is available for the insulation of a roof as well as for the insulation of walls. The different applications influence the necessary compressive strength and hence the required density and material consumption. Therefore the values for the external insulation of a flat roof are clearly worse than the values for a common rafter insulation. Overall, cellulose fibres show the lowest resource depletion. However they only apply for a limited number of installation situations. The highest depletion comes from PUR and extruded PS. Nevertheless figure 2 shows that they might be an option for the external insulation of basement walls as for this special situation only a very limited number of insulation materials is available. All of them figure a comparatively high resource depletion.

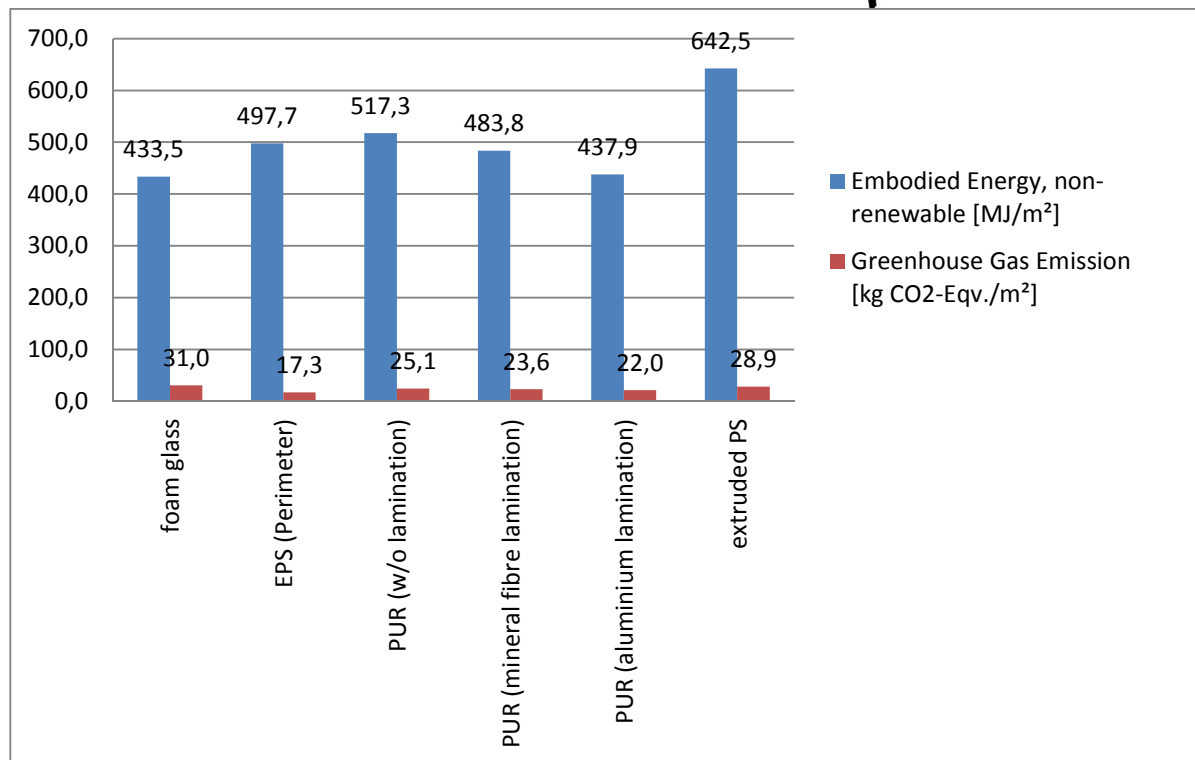


Figure 2: Embodied Energy and Greenhouse Gas Emission for External Insulation of Basement Wall

With respect to the disposal all materials have been marked in red and yellow beside the vacuum isolation panels. This highlightens the need for improvements with regard to the circuitry. So far only vacuum isolation panels partly allow for material utilisation. Often insulation materials are attached to buildings in a manner which does not allow for a sorted demolition. This means that decisions already taken during the planning and construction period hamper a reusage and recycling at the end of life of a building in a number of decades. In order to improve the resource efficiency of insulation materials it is necessary to develop concepts for a sorted demolition of buildings and for a material reusage and recycling.

### Resource Efficiency of Supporting Structures

The resource efficiency of supporting structures has been analysed using the example of a 3 meter high column that is loaded with 100 kN. It has been designed in wood, reinforced concrete and steel. Figure 3 shows the results of a comparison for all four indicators.

		Wood	Reinforced Concrete	Steel
Production	type of raw material	renewable	mineral	mineral/recycled
	embodied energy, non-renewable [MJ]	185,0	118,4	835,4
	greenhouse gas emission [kg CO <sub>2</sub> -Eqv.]	-52,4	17,2	60,6
End of Life	disposal	material/thermal utilisation	recycling/utilisation/disposal	recycling

Figure 3: Comparison of Resource Efficiency of Supporting Structures



Regarding the first indicator, i.e. the type of raw material, wood stands out as a renewable material whereas concrete and steel are of mineral origin. For steel the use of recycling material is positive. The options for disposal of wood and steel have to be evaluated positively as wood applies for material and thermal utilisation and steel can be fully recycled. The disposal of reinforced concrete is improvable as most of it is reutilised for lower-grade purposes and some of it is landfilled while only a small proportion is recycled. The establishment of a recycling for the same purpose i. e. the usage in new buildings offers great potentials for an increase in resource efficiency especially with regard to the large weight of concrete and its wide usage. It can be concluded that wood is clearly the most resource efficient material for supporting structures.

### Conclusions

The used set of indicators show that the resource efficiency varies largely between the different building materials. In order to increase it two major points can be identified: the selection of special materials and the type of construction. The first determines the resource depletion due to the production of the building material whereas the second largely influences the possibilities for a sorted demolition. This is key to a reusage and recycling and central for a significant reduction of resource depletion by the building industry.

### References

- [1] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2012) *Deutsches Ressourceneffizienzprogramm (ProgRes)*, p. 74
- [2] Federal Ministry for Environment, Nature Conservation and Nuclear Safety (2012) *German Resource Efficiency Programme*, URL: <http://www.bmub.bund.de/en/topics/economy-products-resources/resource-efficiency/german-resource-efficiency-programme-progress/>
- [3] Die Bundesregierung (2002) *Nationale Nachhaltigkeitsstrategie "Perspektiven für Deutschland"*, URL: <http://bfm.de/fileadmin/NBS/documents/Nachhaltigkeitsstrategie-langfassung.pdf>
- [4] Informationsportal Nachhaltiges Bauen *Ökobau.dat 2011*, URL: <http://www.nachhaltigesbauen.de/oekobaumat/>
- [5] Institut Bauen und Umwelt e. V. *Umwelt-Produktdeklarationen (EPDs)*, URL: <http://bau-umwelt.de/hp6253/EPDs.htm>



## **“ 0-impact street”, for energy, materials, water and food**

### **Speakers:**

Rovers , Ronald, <sup>1</sup>;

<sup>1</sup> RiBUILT, Research Institute Built environment of Tomorrow, Zuyd University of applied science, Heerlen The Netherlands

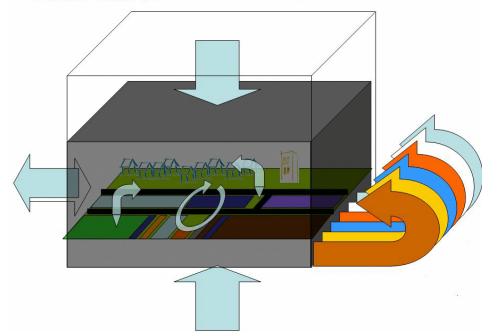
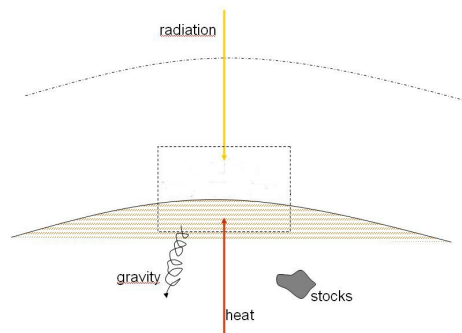
**Abstract:** If we really strive for sustainable solutions, especially sustainable living, its not enough to look only at energy. In that case water and food, are important resources flows to evaluate, and not in the least materials, for our houses and buildings and our “ stuff” that we collect during our active life. And for these resources the same burden applies as for energy: they all help deplete resources, have negative impacts in emissions, are scarce or getting there, and their flows need optimized, in terms of reduction of demand and production from renewable sources. Studies show that the impact of food and materials go beyond that of energy. Which introduces the challenge to not only provide energy form local renewables, but also produce and cycle water, food and materials locally. In short: a 0-impact approach for all 4 resource flows. That’s not viable at a building level, we need to increase the scale level to a street or a district for such an approach. Which is what we currently practice in doing a full thesis design workshop with students, for a real district in the region. The social housing corporation and the municipality act as principal, and have agreed to consider a pilot project in line with these findings.

The paper explores the fundamentals behind a 0-impact approach, evaluates the results of the design charette and from there proposes a model to develop and research for 0-impact streets and districts. The first findings show that this will require a complete “ street make over” in which all available surface has been made productive. At the same time it enhances livability, creates local jobs, and make s the are more resilient in times of streets in global resources supply. The design outcomes will be used to illustrate the potentials and build the case to extend our approach beyond that of energy.

***Keywords, 0-materials, 0-impact, design charette, multi-resource approach, urban redevelopment, sustainable living***

Every system, whether 1 ha of countryside or a km2 built environment, has a certain balance in (resource-) consumptive and productive activities. For a city, as a urban organism, or 'Orbanism', the balance has shifted nearly completely towards a purely consumptive system, On top of that, to supply that demand, it is relying on resources, from uncontrolled sources, globally spread. This creates a very vulnerable situation for city life: a small disruption of the supply chain, and people are trapped in that 'Orbansim', no escape whatsoever, in a ever denser populated world. [1]

The way out or preferred direction of progress, is to make a urban system (or any system ) more vital and resilient, by lowering consumption and increasing production within that system itself. Thermodynamically, all resource use and conversion within a system, will lead



to entropy, and lower quality , in that same system, or , in case of a urban system, a neighboring system, somewhere in the world. Unless this is imported from a productive system (f.i. a country with excess resources) it will deplete other system's resources (plunder). Globally we can safely conclude there is a large overshoot in demand, and eating in on resources. [2] The only escape available, is a source from outside the system, either the urban, local or the global system, being solar radiation in a constant flux adding potential to the earth. Therefore, its obvious that any improvement should be based on maximizing the use of solar radiation within the urban boundaries ( or any- controlled- system border) , as the “capital” to work with. [ill 1] And to bring the total incoming exergy (counter-entropy) in balance with the total consumed quality.

*Ill 1, left The basic system to start from: a defined area, with solar radiation and soil heat , in some cases the use of gravity, and without stocks outside the system.*

*Ill 2, right: The Urban harvest + approach : re use all outgoing flows, cascade flows in the system, and use only free incoming potentials from soil and sky, with a potential to export.*

“Urban productivity “ therefore can only be seen in the light of maximizing capturing solar radiation, or m2 of productive conversion. Either conversion to food products, or to (regrowable) material products, or to human mastered forms of energy . With water harvesting as a side target. ( the water cycle is driven by solar radiation, however on a urban level it can regarded as a separate independent exergy source in the form of rain from outside the system, and not depleting neighboring systems. ) [3]

In summary , it all comes down to intercepting solar radiation, or the ( human knowledge to create) value of any m2 's contribution to productivity, to counterbalance entropy in that system . Odum [4] did some great work on relating system potentials to the solar radiation entering the system, but this requires a extra step in the evaluation in terms of bringing mass into the equation: Mass and energy are in fact two of the same kind, and both subject to similar thermo dynamical laws.

## Sustainability





This also puts the prevailing concept of people, planet and profit, where sustainability is defined as the overlapping parts of all three circles, in a different perspective. There is no such optimum. Society is built on resources, which nature organizes in balance, and on which people have built extensive welfare, creating un-balance (in resources for that same people's needs, not for nature). While policies, regulations and economy are human invented concepts to manage that balance (or better: should manage that balance). They are certainly not an essential part of the balance itself, i.e. they are not a given force, it should be explored how to adapt these to support the balance.

It's about the balance between people and planet that should be (re-) established, with planet as the fixed resource basis (except for the capability to make solar radiation convert those resources) and with people as the – adaptable – load. Economy, policy, religion, are concepts that have to be reinvented to support that balance.

Labels like green economy, circular economy have to be seen as strategies doomed to fail, since they want to combine two completely unequal concepts, unless the economy part will be fully re-developed to support the thermo dynamical balance, in terms of maximizing exergy.

#### **metrics: MAXergy .**

The concept developed to practice this approach called MAXergy (maximizing exergy), with 'Embodied Land' as the un-weighted overall indicator: Land needed to convert solar radiation into a desired form by the human species, i.e. food, energy, materials. It analyses in which way the least embodied land is necessary to provide a unit of function (m<sup>2</sup> embodied land per m<sup>2</sup> shelter, etc). On existing systems level (Urban environment) this is detailed in the Urban Harvest+ approach: A given system is explored, and analyzed how the exergetic demand can be squeezed back within the system borders own potential. [ill 2]

A max potential plan is developed for each resource: generating energy, food, water, and material qualities, and in a next step the integration of all 4 is maximised. It turns out that food and materials are the decisive factors, requiring the most embodied land. [5] In order to bring potential in balance with need or demand, it turns out that a new strategic step is necessary, beside reduction and production, being: re-organisation. It's all about maintaining functions, not about maintaining products: as an example: to develop a A+++ and Cradle to Cradle optimized laundry machine might seem interesting, but is a very limited approach: the function to establish is to clean cloth, which can better be provided with laundry shops. It turns out that exploring the demand with analyzing on a basis of fulfilling functions, leads to interesting options strengthening social cohesion and providing local labor plus a local economy (though not as targets, but as a -positive- side effects). Which is not really astonishing: before the industrial revolution societies already organized more efficiently out of necessity and had more social structures and labor as a bonus. A main conclusion from this research is that it's not about energy at all, but about materials resources (-optimisation) to convert solar radiation into exergetic quality.

### Implementation - practically

Much is possible, can be done, as for instance shown by the municipality of Gussing, Austria: Within system borders they succeeded to produce their own energy, without affecting the other resource potentials. Within their system borders ( the municipality borders) they had enough surface/land available to establish this.[6] It can be modeled in terms of consumptive versus productive systems: How much should a consumptive system be expanded to be able to become a productive system. A matter of floating borders of a system to find balance, and the main question of course is , if there is enough space to have borders widened before another system ( other urban area) is affected. This has to be studied more in-depth, to create a global perspective for potentials.

It seems obvious that there will not be enough land currently to maintain all welfare within carrying capacity (as in “embodied land to convert solar radiation”) globally. Strong reorganization of providing functions ) will be needed, and humans to adapt to new ways of fulfilling their needs , while hoping that most needs can remain to be fulfilled , though probably in other ways. The Brundlandt definition could be adapted in that sense:

*sustainability creates a balance between (re-)sources availability en humand demand for resources in a way that does not deplete sources, does not pollute and does not harm people and nature, and can be maintained towards a future with 9 billion people.*

After having gained experience with low energy pilot projects in the region,[8] the involved stakeholders were interested in a follow up. The interest is fed by the fact that the region has a shrinking population, which leads to a large percentage of empty housing (>4%), and a local policy aimed at demolishing houses. The empty houses are for a large part located in social housing areas with inhabitants in the lower income class. The idea is that this provides room for new initiatives in which the empty houses can fulfill new functions. When optimized from a 0-impact approach new functions can be introduced as well as lower monthly living costs ( energy, urban farming) as well as new jobs /. This makes it worthwhile to explore what exactly would be the potential and consequences of such a approach.

During a regional event called “alliance factory” regional stakeholders come together regularly to explore new projects and cooperation’s. One of the alliances proposed and undersigned was called the “Battle of concepts: 0-impact street” . This agreement consisted of a few activities: A social housing corporation , Heemwonen, selects a real case form its housing portfolio as the study area. This is taken as the case for firstly a student project, exploring and designing a plan to turn this area into a 0-impact street, as part of their graduation thesis. The undersigning stakeholders will form the jury selecting the best plan. The next phase is that the professional stakeholders, based on the findings and ideas of the students, will develop a “counter case” themselves, to explore the actual realization of such a project, as a whole or parts of it. The social housing corporation has agreed to study the actual realization in the selected area. Possibly with support of the “IBA-Parkstad”. Recently the region adopted the plan to establish a IBA in the region, a Internationale Bau-Austellung, a

German developed process for a 10 year innovation process in housing and urban planning. Since the early years of the 20th century many of these IBA's were organized and have led to new insights in housing and urban planning.[8] This project could be part of the regional IBA.

The project has been selected and the student project at time of the WSB14 conference will be finished, and the professional stakeholders plan under way.



*Ill 3: The study area for the student project: 3 streets as part of a restructuring plan of the District*

The selected project is an area of three streets in Western part of the Kerkrade city, totaling 81 houses. The streets are part of a district plan, with large scale renovation, introducing a park zone (from a demolished living area). [ill 3] The houses are small And need a large scale renovation to make them meet modern standards. It was decided from practical reasons that corner houses would be left empty, and can be used for services in the neighborhood, and that all terraced houses in between will be inhabited after the project completion. This provides opportunities for local services without having to invest materials to construct buildings, while at the same time its seen as most probable location for services that can strengthen social cohesion. These corner houses can be of service to the 0-impact concept, as well as for housing a nurse for local care services for instance (the neighborhood is graying, as well as the Dutch governments implement a plan for more participatory society, including living at home as long as possible, with caretaking by children and neighborhood service).

The Bill of Requirements regarding resources for the project has been defined as follows: make a plan for each resource separate, and try to establish the 0-situation: all resources produced within the project system. On the demand side strong reduction has to be established: The goal is to try to deliver all functions and services included, but not necessarily in the same way. (think of sharing options etc)

The 4 plans, energy water materials and food, have to be combined to 1 plan (maximization plan), which is the moment to make decisions: do I use the surface for energy generation or food production? This is the creative process, in which also multilayered potentials have to be introduced (stacking production possibilities).

For energy food and water, the 0 is mandatory overall. However, to obtain this, a lot of materials will be needed. For this reason, regarding materials its only required that the 0 should be within reach after completion of the “ make over” of the area: So the resources for the “ make over” can be “imported to the site” . However under the condition ‘ as little as possible’ , and as much renewable as possible. Maintaining the area afterwards should be



within limits of local production, the 0-approach. The students have to deliver a rough calculation regarding production and reduction possibilities for each resource, and a maximization plan with design how to implement this in the pilot case . Students are required to find most information by themselves, though they are guided with lectures and workshops on different topics.

*Ill 4, left.: Preliminary sketch of one of the design groups: with productive roofs, and corner houses as general facilities.*

*Ill 5, right: Example of current renovation practice in development: 1 day Make over with prefab skin elements, in a inhabited situation*

From the first evaluation of designs, its obvious that greenhouses play a major role in the re-design, it helps boost the urban farming production, and can play a major role in the energy management. [ill.4] All roofs by all groups are reshaped for this reason. The public area is included for use in the productive area, as well as the back gardens of the houses. All design groups so far have plans to use those areas, sometime partially. A main discussions is between students whether these areas should be privately exploited or as a communal area. The backyards, are mainly planned for a common garden for water treatment and materials production. The houses on the corners get mixed functions, among others: repair shop, small communal workshop, space for inhabitants commercial activities (hairdressers, fitness, etc) , care center, communal centre ( “living room” ) etc. To meet energy ambitions is the least of their worries, food and materials are causing the students most of the trouble. Especially finding data. (It is part of the project to have them find their own data, and verify these) .

## Follow up

Last year, local authorities have contracted a research to create a full energy balance of the region, in terms of where there are reductions options at building levels as well as regional level and where are the possibilities for (renewable) energy generation. This led to a document giving guidance in planning a transition , creating the energy balance in the region.



A new initiative is now adopted to complete this research with all other resource flows, so that an integrated approach will be possible.

Regarding the possible pilot of the 0-impact street project, it's currently the preferred direction of development to do renovations in a short time ( up to 1 day), in a inhabited situation, to avoid stress with inhabitants as well as to reduce costs of temporarily re-housing. [ill. 5] However in this case, the consequences are great, both technically as in adaptation to the new situation by inhabitants. For this reason it would be better to first “ empty “ the street, and after completion have potential tenants apply for one of the houses in the area under the new conditions . When we will have the presentation in October the final plans and data can be shown , as well as from the professional stakeholders)

As a general conclusion, its important to further explore the 0-impact approach, to avoid that the environmental burden is shifted from energy sector to the materials sector. Projects like this, are ideal to get insights in the consequences of resources interactions, and to direct innovations and social solutions in the most sustainable direction.

#### References

- 1 Rovers R, (2009), Post Carbon - or Post crash – managing the Orbanism , World Transport Policy & Practice Volume 14. Number 4. April 2009, page 7-17 , <http://www.eco-logica.co.uk/pdf/wtpp14.4.pdf>
- 2 WWF Living planet report (2012)
- 3 Leduc W,. Et all (2009) : Expanding the exergy concept to the urban water cycle, , SASBE conference paper
- 4 Hau, J., et all, (2004) Promise and problems of emergy analysis , Ecological Modelling 178 (2004) 215–225
- 5 Rovers R, et all, (2011) , Urban Harvest+ approach for 0-impact Built Environments, Case Kerkrade West, Journal: International Journal of Sustainable Building Technology and Urban Development Volume 2, Issue 2, June 2011, pages 111-117
- 6 European centre for Renewable energy, <http://www.eee-info.net/cms/EN/>
- 7 Rovers R., (2014) New energy retrofit concept: ‘ renovation trains for mass housing. Paper For BRI journal , Building Research Information, accepted for publication this summer.
- 8 general: [https://de.wikipedia.org/wiki/Internationale Bauausstellung](https://de.wikipedia.org/wiki/Internationale_Bauausstellung) regional: <http://manifestatie.iba-parkstad.nl/nl/over-iba.php>



## Earthen Architectural Heritage (Rehabilitate the earthen construction in Saharan areas for sustainable development) Case of Wilaya of Adrar

M.Hamiane<sup>1\*</sup>; I.Djefour<sup>2</sup>; H.Merabet<sup>3</sup>; D.Bouallala<sup>4</sup>; A.Zekagh<sup>5</sup>; Y.Turki<sup>6</sup>; M.Saidi<sup>7</sup>

<sup>1,2,3,7</sup>Materials Engineering department. URMPE, University of Boumerdes. Algeria

<sup>4</sup>BET Tarchid; Adrar Algeria.

<sup>5</sup>National Office of Management and Protection of Cultural Heritage. Algeria

<sup>6</sup>National Centre for Architecture in Earth. Ministry of Culture. Algeria

### Abstract

*The raw earth is a material used for millennia across all continents. Earthen architecture has many benefits, not only in technical terms (thermal inertia), but also economic (less expensive) and environmental (available and accessible on-site material, requiring no transformation). Using recyclable materials to preserve natural resources, optimizing the thermal inertia of buildings, and integrating renewable energy sources into the building design or eco-construction are the guarantee of sustainable development. Sustainable building should be a priority for construction policy in the south. This policy of sustainable development in the Saharan regions of Algeria will meet the strong demand for housing, preserve cultural heritage and contribute to reviving traditional knowledge to construction ensure appropriate architecture to the needs of the population and to its economic resources and climatic characteristics of the region, as well as the extension of the earthen heritage of the builders. This objective is to guide our work. Developed and designed based on local raw materials, mortars and coatings (plasters), are to be compatible with the historic building to restore and ensure durability. The results of physical and mechanical characteristics of mortar and coatings compositions developed at the laboratory level, showed effective, compatible with the characteristics of construction materials building of the Adrar Hospital.*

**Keywords:** *Earthen construction, mortar, plaster, characteristic, formulation, Sustainable development; Adrar Hospital.*

### 1. Introduction

The earth is the simplest natural material we have at our disposal. It is used by man in construction for thousands of years to build buildings across all continents, with techniques and traditions that are a true living testimony to the history, cultures of peoples, and the identity of places.

Algerian Sahara belongs to the world's largest desert. It is the aridity that characterizes the Saharan climate; water deficit at all levels is due to the low rainfall, the intense evaporation, the high temperatures and the high luminosity.

Under these conditions we find the Adrar wilaya which is about 1540 km of Algiers (Fig. 1). It is characterized by its relatively flat topography and desert geomorphology. In these areas the man has developed construction techniques from the local earth which made the transactions between the requirements of human life and the arid climatic environment. The Adrar hospital (photo 1) our study case is located in the capital of the Wilaya. Its function is to act not only as health care centre but also as preventive establishment and as a school of

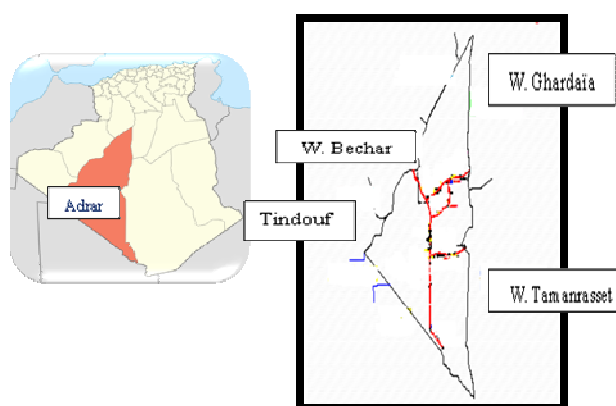


Fig.1 Location of the Adrar hospital

health education. It was created in 1942, designed by French architect of Belgian origin, Michel Luycks . It was built in earth brick (adobe) and earthen mortar. These walls are carriers roof composed of arches of different spans and heights. The adobe (clay, sand and various additions) were made at quarries land outside the city of Adrar. The building has been abandoned since the early 1980s, which marked its degradation. [1]

*Photo 1. The Adrar hospital*

Restoration of Structures of old buildings requires compliance their initial architectures and knowledge of the characteristics of the materials used. To this end, our study aims to characterize the building materials of the hospital, consisting primarily of adobe and mortar. The analytical results will reconstitute identical building materials and therefore a restoration, which is adequate and compatible with the materials of

the monument. Sustainable building should be a priority for development policy in the south. This policy of sustainable development in the Saharan regions of Algeria will meet the strong demand for housing, preserve cultural heritage and contribute to reviving the traditional constructive knowledge, ensure appropriate architecture to the needs of the population and to the economic resources and climatic characteristics of the region, as well as the extension of the earthen

*Photo 2. Infiltration of rain water*

heritage of the builders. It is this objective that guides our work. It is developed based on local raw materials, mortars and coatings compatible with the historic building to restore and ensure durability. The results of physical and mechanical characteristics of mortar compositions and coatings developed at the laboratory level, showed effective, compatible with the characteristics of construction materials of Adrar hospital. [2,3]

## 2. Conservation status of the Adrar hospital

The earthen architecture has evolved through generations using local materials. The earthen material has proven its validity through time, its efficiency in architectural solutions, and the ability to appropriate design against the influence of climatic and environmental factors.

It meets the needs of the population and their social, cultural and economic development. Despite the advantages, strengths and the many features that make the raw earth, which is the first building material in desert areas, other disadvantages should be taken into account and improved to a more efficient use. The hospital is in an advanced state of degradation. This inventory is accelerated in part by the action of many natural factors: rain, moisture, temperature variation, and erosion .On the other hand, by the disastrous consequences of actions and interventions of man on the monument.

Among the most important factors of degradation are visible on the monument, we note: the infiltration of rain water, erosion and loss of mass (bricks and mortars), stagnation of water on the terrace, cracking walls and peeling of coatings. Added to this, the activities that lead man on or around sites such as:

Misuse of the site, the introduction of new materials, poor waste management. The photos from (1 to 4) show some types of these degradations. [4, 5]

*coating*



*Photo N° 4.1 & 4.2. craks and peeling of*

### 3. Experimentation

Eight (08) samples of mortars and coatings were taken for analysis. Samples were subjected to physical characterization, and analysis of mineralogical and chemical composition. The flowchart in Figure 2 shows the methodology followed for these analyses. The tests were performed at laboratories CETIM, URMPE and ceramics laboratory at the University of Bumerdes. The analysis results are shown in Tables 1 to 3.

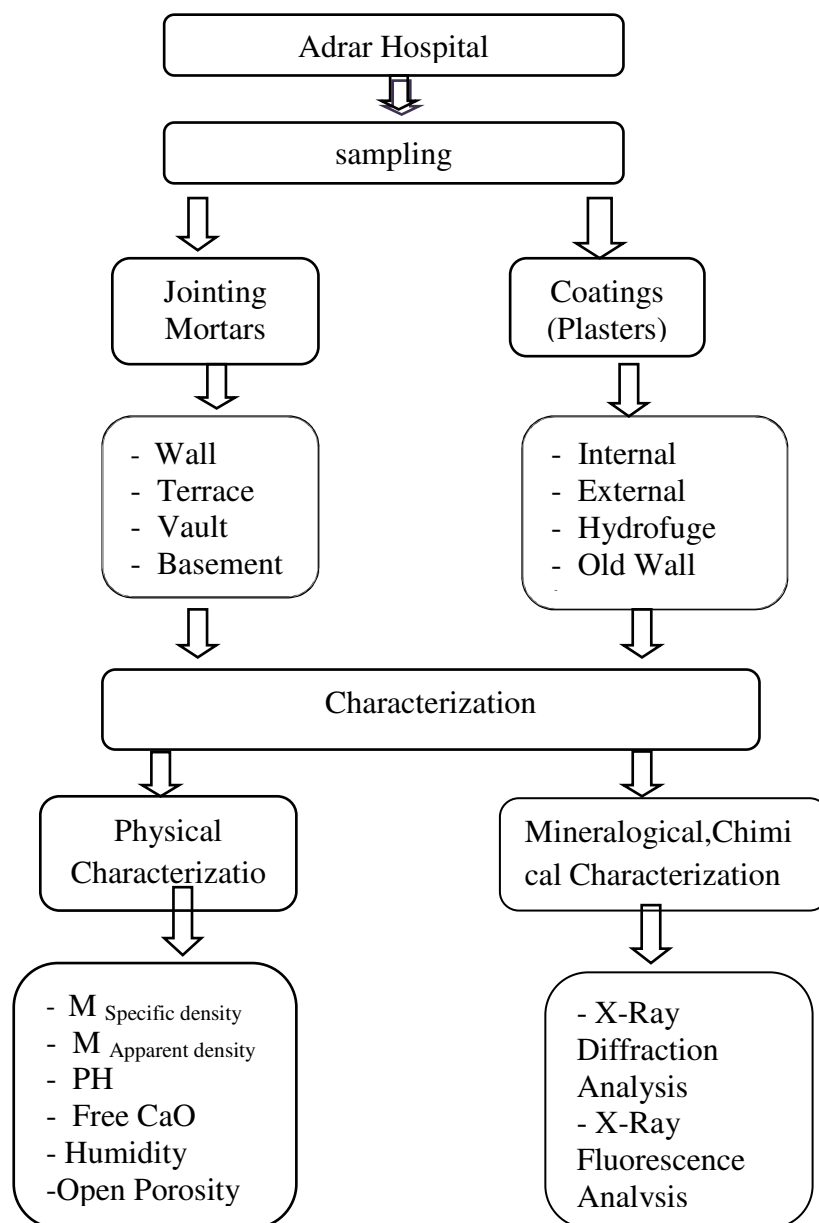


Fig 2. The flowchart shows the methodology followed for these analyses

Table 1: Summary of physical properties of mortars and plasters samples from the Adrar hospital.

N°	Sample		Ms (g/cm <sup>3</sup> )	Mv (g/cm <sup>3</sup> )	H (%)	PH	CaO <sub>L</sub> (%)	P (%)
05	Wall Jointing mortar		2,44	2,01	2,02	8,97	4,48	17.62
06	Basement jointing mortar		2,34	2,15	1,66	8,97	+	8.12
07	Terrace jointing mortar		1,53	1,40	1,14	8,9	+	8.49
08	Vault jointing mortar		2,43	2,23	1,52	8,99	+	8.23
09	Wall old plaster layer	1 <sup>st</sup> layer	2,42	1,95	0,89	9,34	0,89	19.42
		2 <sup>nd</sup> layer	2.32	1,95	1,14	/	1,14	15.94
10	Terrace plaster	1 <sup>st</sup> layer	2,63	1,96	1,51	8,83	1,51	25.47
		2 <sup>nd</sup> layer	1,58	1,30	0,80	8,73	0,80	17.72
11	outer plaster		2,43	1,92	0,64	10,3	5,6	20.98
12	internal plaster	1 <sup>st</sup> layer	1,58	1.20	/	9,01	/	24.05
		2 <sup>nd</sup> layer	2,26	1,78	0,87	10,08	0,87	21.23

Legend: Ms: specific density; Mv: apparent density; H (%): Humidity; CaOL: Free lime; P: Porosity

Table 2: Summary of mineral compositions of plasters samples taken from the Adrar hospital

N°	Composition	internal plaster (First layer)	outer plaster	wall old plaster layer
01	Calcite	+	+	+
02	Halite	-	-	-
03	Anhydrite	+	-	-
04	Gypsum	-	+	+
05	Orthoclase	+	-	-
06	Albite	+	+	-

Table	07	Illite	-	-	+
	08	Kaolinite	-	-	+
	09	Quartz	+	+	+
	10	Dolomite	-	+	-
	11	Sepiolite	-	-	-
	12	Bassanite, high, syn	-	-	-
Adrar	13	Potassium tecto- alumotrisilicate	-	-	+
	14	Feldspar	-	+	-
	15	Aragonite	-	+	-

3. The chemical  
composition of plasters  
samples taken from the  
hospital

N °	Sample's name	loss on ignition (%)	Sum of concentration (%)	SiO <sub>2</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	CaO (%)	MgO (%)	SO <sub>3</sub> (%)	K <sub>2</sub> O (%)	Na <sub>2</sub> O (%)	P <sub>2</sub> O <sub>5</sub> (%)	TiO <sub>2</sub> (%)
01	Internal plaster (1 <sup>st</sup> layer)	12,15	100	58,05	7,44	3,89	10,67	2,17	1,50	2,31	0,96	0,05	0,80
02	Internal plaster (2 <sup>nd</sup> layer)	40,50	100	6,80	1,50	0,58	45,95	1,76	1,74	0,30	0,76	0,04	0,09
03	External plaster	25,30	100	34,41	2,75	1,53	26,28	6,33	1,57	0,76	0,37	0,04	0,66
04	Wall old plaster layer	9,76	100	67,69	5,73	2,86	8,62	1,50	0,73	1,73	0,66	0,03	0,67

## 4. Interpretation

### 4.1. Sampling from the hospital

Representative areas were selected for sampling (mortars and plasters). The main composition of the samples is red clay, except plasters which show white, yellow and red light colors, signifying the presence of lime, sand and some cement. Samples in their majority have low porosity or pore with small white and black grains (sand) and sometimes the presence of gravel, evidence that the raw material taken from quarries has not undergone purification or sifting.

### 4.2. Chemical and mineralogical analysis of samples

Plasters contains quartz, illite, calcite, gypsum or anhydrite, albite and kaolinite, which show that both coatings (old and internal) are prepared from the raw material (clay quarry) with different proportions and additions Adrar sand.



The compositions of the raw materials of adobe, mortars and plasters wall is (80% sand and 20% clay) , basement (80% sand and 20% clay) , terrace (85% sand and 15% clay) , vaults ( 87.5 % sand and 12.5 % clay).

#### 4.3. Physical characteristics

It is noted that the samples have a PH between (8.73 to 10.30), which shows the basic character of the clay due to the mineralogical composition. All samples contained the free lime, proof of presence of carbonate materials. The wall jointing mortar and the outer plaster contain 4.48 % sequentially and 5.6 % of free lime, suggesting the addition of lime is used as a stabilizer with clay. Open porosity of basement, jointing and vaults mortars varies between (8.12 % and 8.49 %), which may explain a better state of conservation of basement and some vaults adobes bricks and mortars.

The values of moisture samples are considered low (it is between (0.64 % and 2.02 %)) , this is due to that the samples were collected , stored, and then measured in an environment where the temperature is high and the humidity is very low. We noted that the open porosity of plasters decrease from the first layer to the last layer.

#### 5. Conclusion.

We note that the red clay main component of mortars and plasters is not highly plastic clay, it does not contain montmorillonite. The red color is mainly due to the presence of iron oxide. The approximate composition of raw materials used for the preparation of mortars, plasters and adobes vary from (12.5 to 20% clay and 80 to 87.5 % sand). These are local raw materials, taken not far from the monument and its surroundings. Basement mortars and vaults have an open porosity between 8.12 and 8.49 % , which partly explain their conservation. Terrace mortars have a porosity of 25.47 % for the first layer and 17.72% for the second layer. Their damage or deterioration is due to storm water infiltration and damage caused by these waters in the monument.

Mortars and plasters contain in their compositions: quartz, calcite, illite, gypsum or anhydrite, which shows that the raw material is composed of local sand dune, red clay or their combination and a percentage of sebkha substances. Mortars and plasters, also emphasize the use of local raw material. Physical characteristics have enabled us to locate these materials in relation to references and formulate compositions that have better performance.

A sustainable development means a development process that balances the ecological, economic and social and establishes a virtuous circle between these three poles. Facing the housing situation took an alarming proportion in Algeria and especially in the south and causing a degradation threatening the quality of life of the population, earth is the material that best satisfies this equation. A recyclable material, abundant, optimizes the thermal inertia of buildings and preserves the traditional know-how and meets the need of housing in areas of southern Algeria.

#### 6. References

- [1]Imane , D., Hafida,M . , Messaoud,H . , (2012), Design and characterization of adobes , mortars and clay plasters for restoration of the Adrar hospital, Boumerdes , Algeria . Magister Thesis , University M'Hamed Bougara Boumerdes , p101 -233 .
- [2]Bruno , P., (2005) , Earthen materials, Technical building and restoration (ed.), Eyrolles, France , pp. 62-75 .
- [3]Hugo , H., Hubert . G., (2006) Treaty of earthen architecture building, (ed.),Incidentally, Craterre , France , P260 -289.
- [4]Messaoud , H., (2011) , Expertise report of the hospital Adrar conservation .Algera.
- [5]Djelloul , D., (2011) , Report of the Study Office of Adrar . (BET Tarchid ) .Algeria

## **Examination and Assessment of the Environmental Characteristics of Vernacular Rural Settlements in Varying Topographies in Cyprus**

### **Speakers:**

Philokyprou Maria<sup>1</sup>; Michael Aimilios<sup>2</sup>; Savvides Andreas<sup>3</sup>; Malaktou Eleni<sup>4</sup>

<sup>1</sup> Department of Architecture, University of Cyprus, Nicosia, Cyprus

<sup>2</sup> Department of Architecture, University of Cyprus, Nicosia, Cyprus

<sup>3</sup> Department of Architecture, University of Cyprus, Nicosia, Cyprus

<sup>4</sup> Department of Architecture, University of Cyprus, Nicosia, Cyprus

**Abstract:** *The proposed paper aims at examining the typological variations of typical traditional dwellings of Cyprus at Pera Orinis and Askas settlements -on the plains and on the mountainous areas respectively- and the ways in which these settlements are adapted to the natural environment. This study is part of a research program being carried out at the University of Cyprus and dealing with the implementation of sustainable design elements of vernacular architecture in traditional buildings, whereby case studies of rural settlements located in different climatic zones are examined. The ongoing comparative study indicates that the traditional dwelling is subject to morphological variations in varying topographies whereby different passive heating and cooling strategies are incorporated in the design of traditional buildings. Research outcomes aim to reveal design considerations for environmental refurbishment solutions of the vernacular built stock.*

***Vernacular settlements, environmental adaptation, passive design strategies, thermal comfort***

### **Introduction**

The environmental design features that have been incorporated in the design of the vernacular buildings vary from their location in the plains to that in the mountainous areas in order to adapt to the local climatic conditions. Variations of local climate, depending on altitude and proximity to the sea, have created a variety of bioclimatic design solutions which are specifically adapted to vernacular rural dwellings of specific regions. Besides the local climatic conditions, the topography in which the rural settlements have been developed changed the building form and led to various configurations which reflect the specific habits, needs and the way of living of the locals. In addition to the accommodation of the family members, the traditional rural dwelling provides a shelter for the livestock and a storage space for food products. A number of various functions of the dwelling which have had to meet different comfort requirements have led to the division of internal dwelling spaces into multiple thermal zones offering thermal diversity in the traditional house.

The main objective of this paper is the examination and assessment of the bioclimatic strategies inherent in the design of vernacular rural buildings in varying topographies and

climatic zones of Cyprus. For this purpose two settlements –namely Pera Orinis and Askas villages– were selected for detailed study (Figure 1A, 1B & 1C). Pera Orinis is located in the Mesaoria plain in the interior of the island –at a latitude of  $35^{\circ}2'N$  and a longitude of  $33^{\circ}15'E$  – at an elevation of 400m above sea level, whereas Askas is located on the Troodos mountain range –at a latitude of  $34^{\circ}55'N$  and a longitude of  $33^{\circ}4'E$  – at an elevation of 900m. Research findings aim to reveal knowledge with regard to the bioclimatic design aspects of traditional architecture in relation to topography, climatic conditions, building typology and materials.

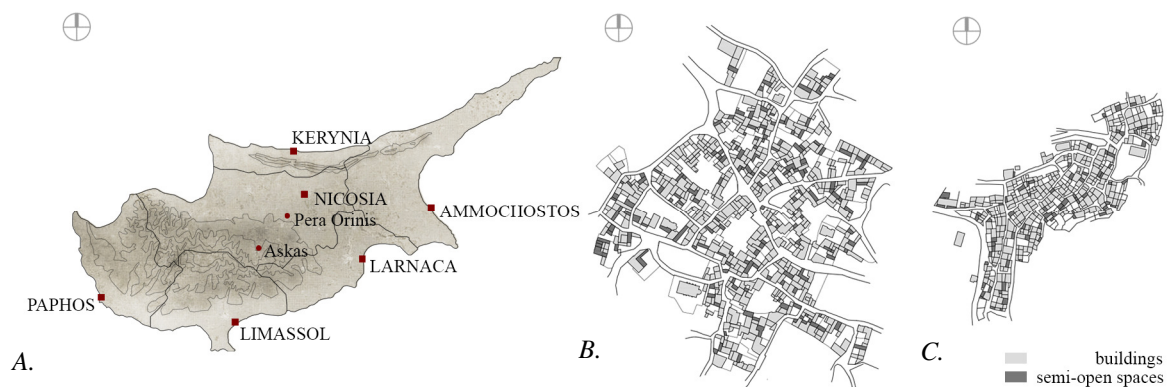


Figure 1 A. Map of Cyprus indicating the two case study settlements B. Pera Orinis village C. Askas village

### Research methodology

The research methodology followed is based on a qualitative investigation of the architectural design aspects of traditional buildings located in the plains and in the mountainous areas of the island. The investigation focuses on a selected sample of traditional dwellings in the two settlements under study. More specifically, an examination of how climatic conditions, topography and available building materials influence the typological, structural and morphological solutions of the buildings is being carried out. Environmental data, architectural drawings and topographical maps as well as on-site observations and interviews with occupants have been collected in order to provide detailed information on the documentation and evaluation of the comfort conditions of traditional dwellings. The layout and orientation of the building mass, the orientation and arrangement of semi-open spaces, the location and size of the openings, the height and the depth of the internal spaces are investigated in order to assess the overall comfort of traditional dwellings.

### Climatic context

The hot and semi-arid Mediterranean climate of Cyprus –characterized by long summer duration, intense summer insolation, great temperature fluctuation and high summer temperatures– has regional variations according to altitude, topographic and geographical factors that demonstrate a variety of composite local climates. Pera Orinis village has short mild winters and hot dry summers with minimal annual rainfall of 342mm and high summer aridity. Minimum temperatures reach  $5.7^{\circ}C$  whereas maximum temperatures reach  $35.5^{\circ}C$ . The village of Askas experiences moderately cold winters and mild summers while annual total precipitation is significantly higher compared to Pera Orinis –reaching 698mm. Lowest and highest temperatures are  $3^{\circ}C$  and  $30.9^{\circ}C$  respectively. In the case of Askas village the

range of temperatures for user comfort is 1°C lower compared to Pera Orinis village (Table 1) [1]. This indicates a difference in thermal perception whereby higher temperatures are acceptable during summer (28.9°C) in the case of Pera Orinis village while lower temperatures are tolerable during winter (17.5°C) in the case of Askas village.

### Traditional dwelling - Environmental design aspects

An overview of the evolution of the typology of the rural traditional architecture of Cyprus shows that the *monochoro* (i.e. single space room) typology, most often in the form of a longitudinal space (*makinari*) is the archetypical shelter of Cyprus. The need for a larger space led to the development of the *dichoro* (i.e. double space room) with an arch or timber beam dividing the room into two parts (Figure 2 & 3). The addition of other rooms for the storage of food products known as *sospito* (i.e. inner house), *sende* (i.e. mezzanines) for crop storage as well as of *anoi* (i.e. upper floor) created various typological configurations [2]. Additionally, the mild winter climate and the harsh summer conditions of the country prompted the incorporation of open and semi-open enclosures in the evolution of the house typology: internal courtyards and transitional spaces such as a semi-open often arched space known as *iliakos* (i.e. solarium) and a pass through semi-open entrance known as *portico* are typical configurations in the traditional house (Figure 2 & 3) [2]. The vernacular dwelling typology has evolved in different forms while adapting to terrain –whether located in the plains or in mountainous areas– to local climate and to the activities of the occupant (e.g. vine-grower, cereal producer etc.). The environmental design features of the traditional house will be discussed below through the comparative investigation of the building stock layout, function, morphology and construction materials of the two settlements under study.

### Settlement compactness, building arrangement and orientation

Settlement compactness and building massing are significant aspects in the thermal performance of buildings. The semi-compact configuration of the village of Pera Orinis allows indirect and direct solar gains during the heating period (winter) while desirable shading from neighbouring surrounding buildings during the cooling period (summer) can be achieved. In contrast, the compact built form of Askas village is more advantageous during the cooling period. It provides protection from intense summer insolation both of the building envelope and of the indoor spaces. However, during the heating period shadows cast by neighbouring buildings causes a significant reduction in useful direct solar gains. With regard to orientation, southern exposure ensures thermal comfort while it offers better availability and distribution of solar radiation throughout the year compared with other orientations [3]. South, southwest and southeast facing buildings account for 44% and 31% of buildings in the

Table 1 Neutral temperature and comfort zone limits (90% acceptability limits) in the four seasons for Pera Orinis and Askas villages using Ashrae Standard 55-2013 ( $T_n = 17.8 + 0.31T_{av}$ )

	T <sub>av</sub> (°C) Pera Orinis	T <sub>av</sub> (°C) Askas	T <sub>n</sub> (°C) Pera Orinis	T <sub>n</sub> (°C) Askas	Comfort limits (±2.5) Pera Orinis	Comfort limits (±2.5) Askas
Winter	10.2	7.2	21	20	18.5-23.5	17.5-22.5
Spring	16.8	13.7	23	22	20.5-25.5	19.5-24.5
Summer	27.7	24.6	26.4	25.4	23.9-28.9	22.9-27.9
Autumn	20.5	17.7	24.2	23.3	21.7-26.7	20.8-25.8

settlement of Pera Orinis and Askas villages respectively (Table 2). Deviations from true south orientation (by more than 30°) incur loss of useful solar heat gains but can still offer benefit from southern solar exposure. In the case of Askas village due to the southeastern-facing slope on which the settlement is located the eastern and southern orientations prevail by 67% of the stock. Eastern orientation (37%) of buildings in the village of Askas is more prone to overheating that may lead to discomfort in case of lack of suitable shading devices [3]. The overall south (S, SE, SW) building orientation in the case of Pera Orinis village offers a better environmental potential whereas topographic challenges in the case of Askas village restrict building location according to prevalent environmental criteria.

### Building form

In the village of Pera Orinis the *dichoro* typology with an attached *sospito* is predominant. The courtyard and *iliakos* that constitute essential parts of the dwelling are fundamental bioclimatic elements integrated in the design [4]. The courtyard provides a buffer zone against cold winter winds, while a southerly orientation ensures desirable solar access to the indoor and outdoor spaces during heating period (winter) and enhances the potential for cross-ventilation in building interiors. The residential buildings of the village have been built to serve the needs of farming where stables, barns and *sende* for crop storage are also incorporated in the building layout (Figure 2A). From the environmental perspective, the traditional house of Pera Orinis while divided into multiple thermal zones (i.e. dark and cool storehouses for the preservation of the food products, enclosed spaces for the main living, semi-open enclosures and outdoor spaces) offers thermal diversity and adaptive opportunities to the occupants. The traditional dwelling of the region is characterized by high ceiling main spaces of approximately 3.5-4.5m and deep spatial layouts. High ceilings reduce the negative effect of excessive solar heat gains through the roof, maintaining indoor spaces cooler during cooling period while at the same time enhance the potential for natural ventilation. On the other hand, deep rooms with openings solely on the front of these spaces restrict uniform distribution of natural light and cause poor daylight conditions to the rear interior spaces.



Figure 2 A. Typical plan layout and section at A. Pera Orinis settlement and B. Askas settlement



In the case of Askas the *dichoro* typology is also prevalent among residential buildings while courtyards do not usually appear in the building layout due to the mountainous topography of the region. Due to the steep slopes of the village of Askas, houses have a smaller footprint on the ground level and rise two or more floors. In this building arrangement the semi-open spaces and living areas are usually found on the upper floors for better solar exploitation during the heating period (winter) (Figure 2B). The southeast-facing slope in which the village of Askas is sited resulted in the inclusion of partially subterranean, windowless spaces at the lower levels of buildings used as storage rooms for locally produced wine and food products. Due to this particular orientation of the settlement the north elevations of buildings which are partly earth bermed provide bioclimatic advantages such as: reduction of exposure of the north side of buildings, shielding of buildings from cold winter winds and thermal buffering due to the contact of the building with the soil mass.

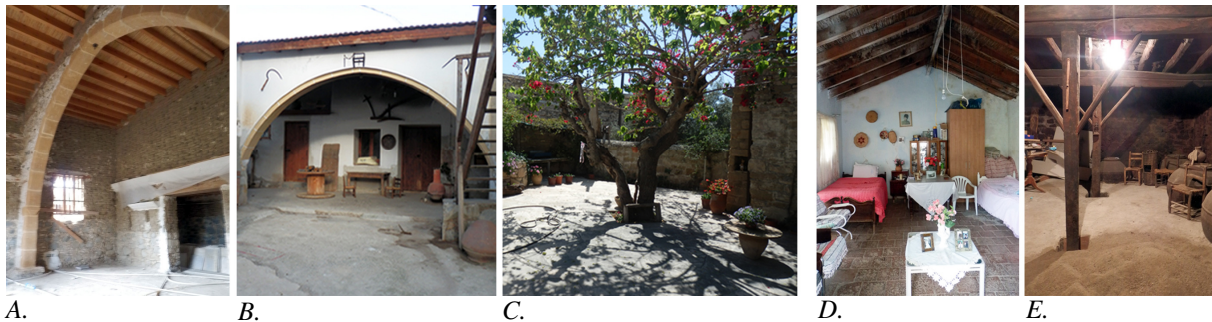


Figure 3 Typological features of the traditional dwelling at Pera Orinis village: A. typical *dichoro* B. *iliakos* C. courtyard and Askas village: D. typical *dichoro* E. subterranean storage space for the food products

### Configuration and orientation of semi-open spaces

Transitional spaces are a vital part of the vernacular architecture of Cyprus. 95% and 53% of vernacular buildings studied at Pera Orinis and Askas villages respectively comprise semi-open spaces (Figure 3B & 3C). The study indicates that while semi-open enclosures are fundamental in the everyday life of the locals in the case of Pera Orinis village, they are comparatively less important in the case of Askas village. This fact is related to the occupant activities as well as to the local climate. The relatively colder winters (heating period) of Askas village discouraged the incorporation of semi-open spaces since such elements result in the reduction of useful solar savings in the heating period even when purposely designed.

In the case of Askas village semi-open spaces appear in the form of balconies, elevated covered verandas and deciduous vine pergolas. The covered part of semi-open spaces is usually narrow in order to allow sun rays to penetrate to the indoor spaces during the heating period and to provide protection from high solar altitude angle during the cooling period. Deciduous vine pergolas which allow solar access during the winter (heating period) and provide shading during summer (cooling period) are preferred in the case of Askas settlement. In the case of Pera Orinis village, the *iliakos* and *portico* are the most widespread forms of semi-open structures. The low- solar altitude angle during the winter (heating period) allows solar penetration to the indoor spaces through the *iliakos* or *portico*, while during the summer (cooling period) these elements prevent the unwanted solar rays to enter the interior rooms

[2]. Southern exposures account for 47% and 36% of semi-open spaces in the case of Pera Orinis and Askas villages respectively (Table 2). In the case of Pera Orinis semi-open spaces exploit the environmental benefits of a southerly exposure to a greater degree.

*Table 2 Orientation of buildings and semi-open spaces at a sample of 122 and 89 traditional dwellings at Pera Orinis and Askas villages respectively*

	N (%)	NE (%)	E (%)	SW (%)	S (%)	S (%)	W (%)	NW (%)
Building orientation- Pera Orinis	13	14	11	6	29	9	14	5
Building orientation- Askas	15	3	37	0	29	2	14	0
Semi-open space orientation- Pera Orinis	7	22	7	8	29	10	7	8
Semi-open space orientation- Askas	19	5	21	5	31	0	17	2

### Building construction materials

Traditional building structure was mainly based on the availability of building materials in the region. The vernacular residence of Cyprus is built exclusively by thick masonry (50-70cm) that provides benefits in terms of its thermal inertia and thermal insulation. Adobe and stone are the most typical building materials found in traditional settlements in the plains and mountainous areas respectively. Both materials are appropriate for hot and dry climates while they act as thermal and humidity regulators. Adobe, made of clay, earth and water mixed with organic substances, is the most common wall material in the case of Pera Orinis village. The measured values of volumetric heat capacity and thermal conductivity, at 336Wh/m<sup>3</sup>K and 0.55W/mK respectively, indicate that adobe is a high-mass material with high heat insulating properties. The local volcanic stones –diabase and gabbro– are the two main building materials in the case of Askas village [4]. The corresponding measured values of volumetric heat capacity and thermal conductivity of the gabbro stone are 522Wh/m<sup>3</sup>K and 1.97W/mK respectively while for diabase are 490Wh/m<sup>3</sup>K and 3.76 W/mK respectively [5]. The volumetric heat capacity of gabbro and diabase indicates that these materials have the ability to store larger amounts of energy in their mass compared to adobe while the higher thermal conductivity value of stones indicates worse heat-insulating properties compared to adobe.

### Sun, daylight and wind access

Moreover, the rural vernacular architecture of Cyprus is characterised by small and sparse openings which are usually inward facing (towards the central yard) due to issues of safety, constructability and environmental performance. Opening sizes and arrangement are significant determinants of daylight and thermal conditions of indoor spaces. In hot and semi-arid climates the ratio of window area to floor area must not exceed 15-20% to avoid overheating during hot summers [3]. Moreover, the minimum net glazing area should not be lower than 10% of floor area to allow sufficient daylight. Studies in traditional buildings at Pera Orinis and Askas villages have shown that traditional dwellings have average window-to-floor ratios of 5% and 4% respectively. Thus, the window openings fail to ensure adequate daylight into rooms but offer protection from undesirable summer sun. With regard to wind penetration, the building mass and window openings arrangement affects natural ventilation conditions of the indoor spaces. The compactness of both settlements restricts cross-ventilation where windows are only placed on one side of the building. Additionally, the

dimensional characteristics of the indoor spaces -ceiling height and plan depth- are significant factors affecting natural ventilation. For sufficient single-sided natural ventilation the plan depth should not be more than 2 to 3 times the height of the space while for cross-ventilation plan depth can be up to 6 times the height [6]. In the case of Pera Orinis and Askas villages the high ceiling main rooms and the thin plan layout arrangements respectively provide the circumstances for sufficient air flow. Average plan depth is 2 and 1.7 times the height of the building (single-sided ventilation) for Pera Orinis and Askas villages respectively.

## Conclusions

The present study identifies and assesses the varied environmental design aspects of the traditional rural dwellings of Cyprus in the plains and mountainous regions. In the case of traditional dwellings at Pera Orinis village –located in a plain– the short mild winters (heating period) and harsh summers (cooling period) result in the enhancement of passive cooling strategies through the semi-compact settlement arrangement, the semi-open and open spaces, the limited openings, the high-mass building envelopes, the high ceilings and a southerly layout prevalence. On the other hand, in the case of Askas village –located in a mountainous region– the moderately cold winters (heating period) and mild summers (heating period) have led to balanced environmental concerns for both summer and winter periods. The compact arrangement, the high-mass building envelopes, the thermal buffering through the soil mass, the geometrical characteristics of semi-open spaces for optimal solar exploitation, the thin plan layout and the additional consideration for direct solar gains during winter (heating period) and solar protection during summer (cooling period) are the main passive strategies inherent in the design of the Askas traditional house. The analysed passive responses have revealed that the integration of semi-open and open spaces in the building layout of Askas village is relatively less important compared to Pera Orinis village. Topographic challenges in the case of Askas village restrict the predominance of southerly exposures while small window-to-floor ratios observed in the traditional buildings of both settlements cause daylighting problems. The above preliminary study revealed that the vernacular dwelling of Cyprus is adapted to the natural environment offering a variety of environmental design solutions specifically applicable to a region. However, topography, construction and security reasons lead to some limitations in this process. Further investigation is being conducted in selected buildings for an in depth, quantitative documentation of the bioclimatic features of vernacular architecture. This study will help towards the establishment of a bioclimatically based approach in the rehabilitation of the built heritage.

## Acknowledgements

The research described in this paper is based on the findings of the research program entitled “Implementation of Sustainable Design Elements of Vernacular Architecture in the Rehabilitation of Traditional Buildings and in the Design of New Structures” funded by the University of Cyprus.

[1] Ashrae (2013). *Ansi/Ashrae Standard 55-2013: Thermal environmental conditions for human occupancy*. Ashrae



- [2] Sinos, S. (1976). *Review of the vernacular architecture of Cyprus*. Athens
- [3] Yannas, S. (1994). *Solar energy and housing design Volume 1*. London. A.A
- [4] CCEAA (2003). *Restoration and maintenance of traditional settlements*. Nicosia. Cyprus Civil Engineers and Architects Association
- [5] Florides, G. et al (2013). Modelling and assessment of the efficiency of horizontal and vertical ground heat exchangers. *Energy journal*, 655-663
- [6] Baker, N. (2007). *Natural ventilation strategies for refurbishment projects Technical Monograph 3*. Revival Project. European Union

## **Análisis de la contribución de los aislantes a impactos provocados y evitados en Edificios**

### ***Abstract:***

*Los aislantes producen una serie de impactos medioambientales, que pueden ser recogidos en las declaraciones ambientales de producto, a diferencia del resto de materiales, no solo los producen sino que también pueden llegar a evitarlos. El análisis de esta contribución es un concepto, que reflejaría los impactos que provocan así como los que permiten evitar a lo largo de la vida útil, en el edificio donde se instalen. Este estudio debería realizarse tanto a nivel de ciclo de vida del material como la implicación de los mismos en los variados sistemas de certificación de edificios.*

*El análisis de ciclo de vida (ACV) de una material aislante es la base, para realizar una evaluación de los diferentes impactos provocados, desde la cuna hasta la tumba, por lo que no solo se deben tener en cuenta la extracción de materias primas, proceso de producción, transporte, residuos generados... sino que también, se evaluara como repercute en un edificio para evitar los impactos asociados a la energía ahorrada, debido a su función de aislamiento.*

### ***Abstract:***

*Insulating produce some environmental impacts, that can be show in the Environmental Product Declarations, unlike other materials, these produce and can be avoided. Analisis of this Contribution is the concept, reflecting the impact created as well as allowing prevent over life, in the building where they are placed. This study will be done both at the material life cycle as involving them in building certitifaction systems (LEED / BREEAM / VERDE / ....)*

*The life cycle analysis ( LCA) of an insulating material is the basis for an assessment of the various impacts arising from the cradle to the grave , so that not only should consider the extraction of raw materials, production process , transport, waste ... but also , as impacts will be evaluated in a building to avoid the impacts associated with the energy saved due to their isolation function .*

***Insulating, Life Cicle Analisis, Mineralwool, Environmental Product Declarations, Impact, Insulation***



## 1. Introducción:

En Europa, el 40% de la energía que se consume es debida a los edificios, siendo una de las mayores fuentes consumidoras de energía, junto con el transporte (34%) y la industria (26%). La reducción de este consumo pasa por un estudio exhaustivo que pueda reducir la demanda energética de manera drástica, para evitar en consecuencia el impacto que provocan al medio.

Los materiales que conforman los edificios son la base para el estudio del consumo energético. Conociendo los impactos que provocan, se puede localizar los parámetros que se pueden reducir con más facilidad.

El Análisis de Ciclo de Vida es una herramienta para evaluar los parámetros de los diferentes materiales que componen un edificio y permite unificarlos, para que resulten sencillos a la hora de introducirlos en la matriz.

Los aislantes producen una serie de impactos medioambientales, que pueden ser recogidos en las declaraciones ambientales de producto, a diferencia del resto de materiales, no solo los producen sino que también pueden llegar a evitarlos. El análisis de esta contribución es un concepto, que reflejaría los impactos que provocan así como los que permiten evitar a lo largo de la vida útil, en el edificio donde se instalen. Este estudio debería realizarse tanto a nivel de ciclo de vida del material como la implicación de los mismos en los variados sistemas de certificación de edificios (LEED / BREEAM / VERDE / ....)

## 2. Certificaciones de Edificios:

Las certificaciones de edificios (LEED / BREEAM / VERDE / ....) a medida que evolucionan los procesos de certificación de los diferentes casos de estudio y las actualizaciones de sus herramientas, empiezan a realizar un cálculo más exhaustivo de los diferentes parámetros que se obtienen en los diferentes criterios. Como es el caso de LEED v.4, que además de los parámetros de material reciclado y transporte desde fábrica hasta la obra, empieza a introducir datos medioambientales recogidos en las declaraciones ambientales de productos.

En la siguiente tabla se pueden extraer los diferentes valores que se necesitarían de una lana mineral para las certificaciones LEED v.3. y V.4, BREEAM y VERDE:

P0051 Panel Fieltro					02/02/018			099/CPD/A43/0213			020/002816			A1			0,039W/m·K			T3-MU1-WS		
					VERDE			LEED V.3			BREEAM / LEED V.4											
					Módulos A1-A3			Módulo A4			Módulo A5											
					E. PRIMARIA			Kg/m <sup>2</sup> cálculo transp			Residuos Kg/m <sup>2</sup>			% material reciclado pre-consumer			% en peso del producto extraído y fabricado a más de 500 millas (aprox. 800 kms)			% en peso del producto extraído y fabricado a menos de 500 millas (aprox. 800 kms)		
Código	Espesor mm	Ancho m	Largo m	Resistencia térmica m <sup>2</sup> ·K/W	M/m <sup>2</sup>	CO <sub>2</sub> kg/m <sup>2</sup>																
2075018	50	0,60	1,35	1,25	22,95	1,08	0,80	0,167	≥ 35	6%	94%	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2075019	60	0,60	1,35	1,50	26,50	1,29	0,96	0,201	≥ 35	6%	94%	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2132675	75*	0,60	1,35	2,00	32,10	1,60	1,25	0,251	≥ 35	6%	94%	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

\* Espesores 75 mm Lambda 0,039/0,038 W/m·K

Imagen 1: Tabla de datos específicos para las certificaciones LEED v.3-v.4, BREEAM y VERDE

### 3. Declaraciones Ambientales de Producto:

Las Declaraciones ambientales de Producto (DAP ó EPD) basadas en la Norma ISO 14025 e ISO 21930 recogen la información ambiental evaluada en el ciclo de vida de un producto. En el caso de los materiales aislantes, en especial las lanas minerales de vidrio, la DAP se basa en las Reglas de Categoría de Producto (RCP) 001 Productos aislantes térmicos.

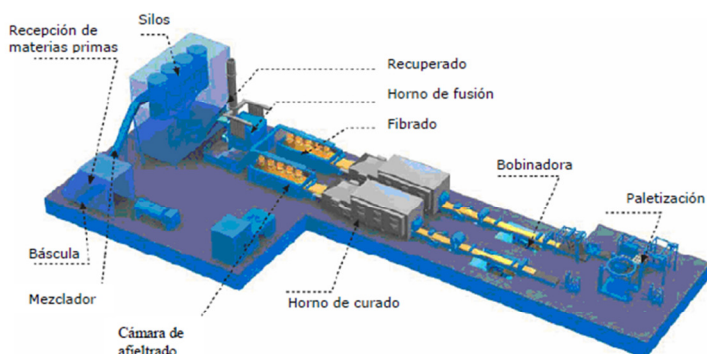


Imagen 2: Proceso de Fabricación de la lana mineral de vidrio

Describen las diferentes etapas del ciclo de vida del Producto: Materias Primas (Módulo A1 y A2), Fabricación (Módulo A3), Transporte del Producto (Módulo A4), porceso de instalación del producto y construcción (Módulo A5) y fin de vida (Módulo C1, C2, C3 y C4), dado que no se contemplan cargas ambientales durante la uso del edificio, no se referencia a los Modulos B1 al B7.

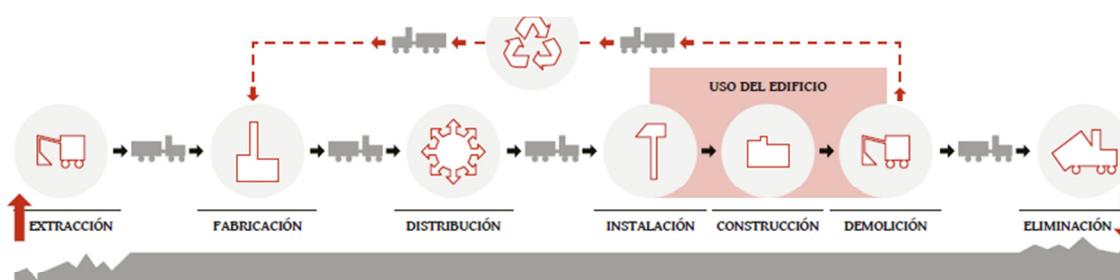


Imagen 3: Ciclo de vida del Producto (ACV)

El análisis de ciclo de vida de la lana mineral de vidrio sigue las normas ISO 14040 e ISO 14044. Partiendo de la unidad funcional:

*“Aislamiento térmico de 1m<sup>2</sup> de fachada durante 50 años utilizando el producto lana mineral con una resistencia térmica de 1,25 m<sup>2</sup>·K/W y considerando un entorno geográfico y tecnológico de España en el año 2010” (DAPc.001.002 )*

Y teniendo en cuenta los escenarios, tales como, el transporte (consumo de combustible, capacidad de utilización, densidad de carga del producto y el factor de cálculo de la capacidad del volumen), procesos de Instalación (residuos en el lugar de instalación), uso operacional de energía y agua (vida de servicio de referencia), mantenimiento y reparación (vida de servicio

de referencia) y fin de vida (procesos de recopilación, eliminación final), así como los parámetros ambientales que se van a evaluar:

- Potencial de Calentamiento global (Kg CO<sub>2</sub> equiv.)
- Potencial de Agotamiento de Ozono Estratosférico (Kg CFC11 equiv. )
- Potencial de Acidificación (Kg SO<sub>2</sub> equiv.)
- Potencial de Eutrofización (Kg)
- Potencial de Agotamiento de Recursos Abióticos (Kg Sb equiv.)
- Potencial de Formación de Ozono Fotoquímico (Kg ethane equiv.)
- Consumo de energía primaria renovable (MJ)
- Consumo de energía primaria no renovable (MJ)
- Utilización de combustibles secundarios no renovables (MJ)
- Utilización de combustibles secundarios renovables (MJ)
- Consumo de agua dulce (m<sup>3</sup>)
- Producción de residuos (Kg)
  - Peligrosos (Kg)
  - No peligroso (Kg)
  - Radioactivos (Kg)
- Material de salida para (Kg)
  - Reutilización (Kg)
  - Reciclaje (Kg)
  - Valoración Energética (Kg)

A partir de estos datos de partida se realiza el inventario de ciclo de vida del producto y los indicadores de la evaluación de impacto, según los parámetros anteriormente citados y en cada una de las etapas del ciclo de vida:

Tabla 2. Indicadores de la evaluación de impacto																
Parámetro evaluado	Unidad por m² de panel	Etapas del ciclo de vida														
		Fabricación		Construcción		Uso							Fin de vida			
		A1. – A3.	A4.	A5.	B1.	B2.	B3.	B4.	B5.	B6.	B7.	C1.	C2.	C3.	C4.	
Potencial de Calentamiento Global	kg de CO <sub>2</sub> eq.	1,08E+00	4,49E-01	1,15E-01	-	-	-	-	-	-	-	-	3,50E-03	0,00E+00	1,31E-02	
Potencial de Agotamiento de Ozono Estratosférico	Kg de CFC11 eq.	6,90E-08	8,59E-10	1,21E-10	-	-	-	-	-	-	-	-	6,71E-12	0,00E+00	1,12E-12	
Potencial de Acidificación	Kg de SO <sub>2</sub> eq.	6,18E-03	2,93E-03	3,59E-05	-	-	-	-	-	-	-	-	2,17E-05	0,00E+00	5,58E-05	
Potencial de Eutrofización	Kg de PO <sub>4</sub> <sup>3-</sup> eq.	8,12E-04	4,66E-04	2,16E-04	-	-	-	-	-	-	-	-	3,43E-06	0,00E+00	7,36E-06	
Potencial de Agotamiento de Recursos Abióticos	Kg de Sb eq.	8,49E-03	3,02E-03	3,30E-05	-	-	-	-	-	-	-	-	2,36E-05	0,00E+00	4,99E-05	
Potencial de Formación de Ozono Fotoquímico	kg de etano eq.	4,40E-04	2,65E-04	3,45E-05	-	-	-	-	-	-	-	-	1,84E-06	0,00E+00	8,86E-06	

A1. Suministro de materias primas

A2. Transporte

A3. Fabricación (según figura 3)

A4. Transporte

A5. Procesos de instalación y construcción

B1. Uso

B2. Mantenimiento y transporte

B3. Reparación

B4. Substitución

B5. Rehabilitación

B6. Uso de la energía operacional

B7. Uso del agua operacional

C1. Deconstrucción y derribo

C2. Transporte

C3. Gestión de residuos para reutilización, recuperación y reciclaje.

C4. Eliminación final

-: las RCP no prevén el cálculo de este impacto al no ser relevante para este tipo de producto.

Imagen 4: Indicadores de la Evaluación de impacto

Tabla 3. Datos de inventario de ciclo de vida

Parámetro evaluado	Unidad por m <sup>2</sup> de panel	Etapa del ciclo de vida														
		Fabricación		Construcción		Uso							Fin de vida			
		A1. – A3.	A4.	A5.	B1.	B2.	B3.	B4.	B5.	B6.	B7.	C1.	C2.	C3.	C4.	
Consumo de energía primaria renovable	MJ (valor calorífico neto)	2,75E+00	1,17E-02	3,52E-03	-	-	-	-	-	-	-	-	9,15E-05	0,00E+00	7,27E-03	
Consumo de energía primaria no renovable	MJ (valor calorífico neto)	2,02E+01	6,31E+00	7,32E-02	-	-	-	-	-	-	-	-	4,93E-02	0,00E+00	1,08E-01	
Utilización de combustibles secundarios no renovables	MJ (valor calorífico neto)	0,00E+00	0,00E+00	0,00E+00	-	-	-	-	-	-	-	-	0,00E+00	0,00E+00	0,00E+00	
Utilización de combustibles secundarios renovables	MJ (valor calorífico neto)	0,00E+00	0,00E+00	0,00E+00	-	-	-	-	-	-	-	-	0,00E+00	0,00E+00	0,00E+00	
Consumo de agua dulce	m <sup>3</sup>	8,85E-03	1,85E-04	6,21E-05	-	-	-	-	-	-	-	-	1,45E-06	0,00E+00	1,79E-04	
Producción de residuos	kg	1,62E+00	2,04E-02	1,67E-01	-	-	-	-	-	-	-	-	1,59E-04	0,00E+00	6,87E-01	
Peligrosos	kg	6,37E-03	0,00E+00	0,00E+00	-	-	-	-	-	-	-	-	0,00E+00	0,00E+00	0,00E+00	
No peligrosos	kg	1,62E+00	2,04E-02	1,67E-01	-	-	-	-	-	-	-	-	1,59E-04	0,00E+00	6,87E-01	
Radioactivos	kg	9,05E-04	1,14E-05	2,13E-08	-	-	-	-	-	-	-	-	6,92E-08	0,00E+00	0,00E+00	
Material de salida para	kg	8,29E-02	0,00E+00	0,00E+00	-	-	-	-	-	-	-	-	0,00E+00	0,00E+00	0,00E+00	
Reutilización	kg	0,00E+00	0,00E+00	0,00E+00	-	-	-	-	-	-	-	-	0,00E+00	0,00E+00	0,00E+00	
Reciclaje	kg	8,29E-02	0,00E+00	0,00E+00	-	-	-	-	-	-	-	-	0,00E+00	0,00E+00	0,00E+00	
Valoración energética	kg	0,00E+00	0,00E+00	0,00E+00	-	-	-	-	-	-	-	-	0,00E+00	0,00E+00	0,00E+00	

A1. Suministro de materias primas  
A2. Transporte  
A3. Fabricación (según figura 3)  
A4. Transporte  
A5. Procesos de instalación y construcción

B1. Uso  
B2. Mantenimiento y transporte  
B3. Reparación  
B4. Substitución  
B5. Rehabilitación  
B6. Uso de la energía operacional

C1. Deconstrucción y derribo  
C2. Transporte  
C3. Gestión de residuos para reutilización, recuperación y reciclaje  
C4. Eliminación final

-: las RCP no prevén el cálculo de este impacto al no ser relevante para este tipo de producto.

Imagen 5: Inventario de Ciclo de Vida (ICV)

Partiendo de estas declaraciones ambientales de productos, se pueden valorar y mejorar los procesos de fabricación para disminuir los impactos que provocan los productos. Como siguiente paso un estudio permonorizado del entorno, localización y orientación del edificio en el que se van a instalar los productos y las diferentes simulaciones energéticas así como las propias certificaciones de edificios, son herramientas en las que se tienen que basar el cálculo de impactos evitados por las lanas minerales.

#### 4. Conclusiones:

El análisis de ciclo de vida (ACV) de una material aislante es la base, para realizar una evaluación de los diferentes impactos provocados, desde la cuna hasta la tumba, por lo que no solo se deben tener en cuenta la extracción de materias primas, proceso de producción, transporte, residuos generados... sino que también, se evaluara como repercute en un edificio para evitar los impactos asociados a la energía ahorrada, debido a su función de aislamiento, en el caso de estudio, un metro cuadrado de lana mineral de vidrio (Conductividad térmica de 0,032 W/m·K y 100 mm de espesor) puede ahorrar el equivalente a unos 400 litros de petróleo durante su ciclo de vida, así como puede prevenir la emisión de 343 Kg de CO<sub>2</sub> durante su ciclo de vida. Otro dato a tener en cuenta es la reducción de CO<sub>2</sub> es 250 veces mayor que el CO<sub>2</sub> generado durante la producción y transporte. Por lo que hay que ir más allá y analizar como puede ayudar a que se eviten diferentes impactos que surgen en el uso de vida de un edificio, así como en la climatología en la que se encuentre.



En el escenario de transporte que se ha tenido en cuenta se ha considerado que la lana mineral de vidrio, debido a ser una lana mineral de baja densidad se puede comprimir hasta 8 veces, por lo que hace que el transporte sea bastante eficiente, para ser un material de construcción.

Intrínsecamente, llevará una mejora del confort de los usuarios de ese edificio así como un ahorro económico.

## **5. Referencias**

Agende de la Construcció Sostenible. (2010) Declaración Ambiental de Prestaciones DAPc.001.002.

UNE-EN ISO 14025:2010. Etiquetas y declaraciones ambientales. Declaraciones ambientales tipo III. Principios y procedimientos.

UNE-ISO 21930:2010. Sostenibilidad en la construcción de edificios. Declaración ambiental de productos de construcción

Imagen 1: Catálogo de Declaraciones Ambientales de Productos de Construcción URSA

Imagen 2: URSA

Imagen 3: Informe de Sostenibilidad URSA 2012

Imagen 4: Declaración Ambiental de Prestaciones DAPc.001.002.

Imagen 5: Declaración Ambiental de Prestaciones DAPc.001.002.





## **Towards Creating New Sustainable Cities in Egypt- Critical Perspective for Planning New Cities**

### **Speaker:**

Ellahham, Nisreen<sup>1</sup>

**Abstract:** *The objective of this paper is to form a future vision of Egyptian sustainable cities that integrates theories with international experiences. The paper highlights the pressing need to establish new areas for development in the Egyptian desert—through geo-economic restructuring of Egypt—that would contribute to reduction of population density in existing cities through attracting it from the narrow congested valley to new urban communities. This helps destabilize the existing urban density, which has become already experiencing severe environmental degradation.*

*The paper identifies the most important theories of sustainable cities and sets their establishment standards and planning criteria. It analyzes the pros and cons of the Egyptian experience in building new cities in the desert and the major pertinent impediments. The ultimate objective is to sketch strategic orientation, based on results reached and lessons learned, for the purpose of establishing new sustainable urban communities in the Egyptian desert.*

### ***Egypt - desert - sustainable – cities***

#### **Concept of sustainable cities**

The concept of "sustainable cities" emerged concurrently with the adoption of sustainable development concept and the increasing concern about impacts of development on the physical, social and cultural environment. Related to the main philosophy of Sustainable development, the sustainable cities concept called for identifying a new type of cities that would achieve economic growth through an economic base that does not drain or pollute natural resources, adopt products recycling or restoring the invested energy. Also, sustainable cities achieve social equity for their residences in a manner that strengthens the concepts of democracy, participatory decision making, and self reliance. Sustainability of the city is fulfilled by the self reliance of its community, meeting its basic needs, minimizing the poor – rich and different income levels gap, securing the minimum level of the acceptable life standard to all members of the community, ensuring participation and accountability along with using technical technologies compatible with the local circumstances.

In addition, sustainable cities are green, environment-friendly cities where the absorptive capacity of resources and local environmental systems are balanced. This balance would be achieved by upgrading the resources usage efficiency, and attaining the minimum level of polluted outputs in order to enable renewal of the ecological system, and preventing pollution by minimizing waste. The sustainable city should be zero or low carbon emissions, hence, contributing to decreasing the production of Carbon dioxide and other organic composite which amplify climate change. This entails decreasing the use of fossil fuel to the lowest level, while concurrently increasing the use of new and renewable energy.

---

<sup>1</sup> Information & Decision Support Center, Cairo, Egypt



### **Basis of planning new sustainable cities**

Through conducting literature review concerning planning sustainable cities and revising some successful international experiences in constructing sustainable cities, the basis of planning a new sustainable city are concluded as follows:

- Planning process of the new city is carried out according to certain criteria: 1. developing the new city according to an integrated master plan, 2. taking in consideration the principles of urban design while concurrently maintaining natural environment, 3. lending the new city an independent social, geographic identity and local administration, 4. achieving large scale self sufficiency to ensure meeting the needs of different residents categories.
- The adequate site for the new city that should be selected based on the competitive advantage in terms of: elements of economic development, accessibility to the site, its geography, type of earth, and cost of constructing the infrastructure.
- The optimal size of the new city should be identified before constructing the city to ensure adequacy for the purpose and planned job opportunities.
- The infrastructure and comfortable and adequate public transportation provided to all segments of the society stands as main element for attracting residents to the new cities.
- Depending on sources of alternative energy specially sources of competitive advantage which achieve economic and environmental sustainability of new cities.
- Administration of new cities applied in three formats: 1. central allowing coordination between the programs of constructing different new cities, and enforce strict control over investments, 2. decentralized whereby promoting competition among regions and municipalities, 3. central planning and decentralized implementation allowing the central government to control housing policies, expanding competences of the municipalities in a manner that allows them apply certain policies for attracting private sector and engaging the local community in planning and implementing the city, however, the process is carried out under the supervision and monitoring of the central government.
- Funding of the new city is processed through: 1. complete governmental funding policy which may cause an imbalance of different development areas, government incurs the burden of providing huge investments, and the government rather than individuals will secure the profits; 2. private sector policy which mitigates the government's burden, though, does not ensure achievement efficiency; 3. government – private sector funding participatory policy allowing to attract private investments, and settling the new city's loans taken from the government during the initial phases.

### **The Egyptian experience in creating new cities**

During the seventies of the last century, interest grew in the idea of new urban communities in Egypt. In this regard, the State adopted creating a number of new cities aiming to decrease the



high population density, mitigate the burden off the existing areas and cities by means of stretching out to the desert and constructing urban communities which would absorb part of population accumulation in different cities within the national planning. For this purpose, New Urban Communities Authority had been established by virtue of Law 59/1979 to serve as the responsible body for creating, administering, selecting sites, and preparing master and detailed plans of new cities. A development and construction map had been prepared for Egypt covering till 2017 including assignment of 24 new cities reflecting new urban communities aiming to absorb 12 million people which is 50% of the expected annual increase till 2017.

The new cities in Egypt are broken down in terms of sites and functions as follows:

- Satellite cities: which are located around and close to Cairo with a short and middle term objective of minimizing population density, and benefiting of the available basic structures such as services, and labor in attracting population, activities, creating new job opportunities, and economic elements that are associated with the mother city, such as 15<sup>th</sup> May, 6<sup>th</sup> of October (first generation cities), Badr and Obour cities (second generation cities). The aforementioned cities do not have an economic base, but they rather fully depend on the mother city. Eventually, this makes them turn into additional burden.
- Twin cities: which reflect an urban expansion into desert land; they are usually constructed adjacent to the existing cities. In some cases, they are considered a natural extension to the existing cities; such as for example new Damietta, new Beni Suef, new Minia (second generation cities), new Asuit, new Akhmim, and new Aswan (third generation cities). The aforementioned cities have their own economic and service base; nevertheless, they are closely connected with the twin existing city.
- Independent cities: which are located distant from the existing cities enough to support their independence. These cities are characterized with high absorptive percentages, an economic base that would – on the long term – allow them create around them independant economic entities serving as economic growth poles, and compiling different socio-economic activities. The said cities may stretch deep into the desert away from the valley's strip including for example; 10<sup>th</sup> of Ramadan, Sadat, New Borg el A`rab and Salhia cities (first generation).

### **Most important pros of the new cities in Egypt**

- Urban expansion and stopping creeping over agricultural areas: Informal growth trend had continued over the urban border of Egyptian cities, yet, the 750 Feddan total area of the new cities would have been deducted from the cultivated areas in the Valley and Delta for urban expansion, in case the cities were not built (New Urban Communities Authority 2010).
- Industrial expansion and providing new job opportunities: New cities allowed a chance to set up industrial facilities because they provide the necessary areas required for establishing factories and their future extensions, and accessibility to internal and external marketing centers. Therefore, private sector's investments flowed massively to the new cities creating



additional national product to Egypt's industrial map. The new cities host 21 industrial zones with total area of 37,113 Feddan, number of productive plants until 31 December 2011 came to 5449 with a total capital of L.E 158 billion and total production of L.E 287 billion (Industrial Development Authority 2011).

Until the aforementioned date, the said factories provided 511 thousand job opportunities and the number of under construction factories came to 2967 which would provide 97 thousand job opportunities. (New Urban Communities Authority 2011).

- Providing housing: In 2011, total number of population in new cities came to 5 million which is expected to reach 17 million when the cities are completely grown. In 1980-2011, 1.2 million housing units had been implemented broken down as 350 thousand by the Authority and 850 thousand by the private sector and other entities. Currently, implementation of the Social Housing Program is underway and expected to implement 100 thousand housing units for the limited income category in the new cities. 155 thousand residential land plots had been allocated including 86 thousand for low and middle level scoring 62%, and 59 thousand plots for upper middle forming 38% (New Urban Communities Authority 2011).

#### **Most important cons of new cities:**

- Unemployed capacities in the housing area: Percentage of population attraction failed to attain the targeted numbers as more than 40% of the housing units were reported vacant in 1996. Several reasons stand behind this failing trend including: high rent, inadequate payment installment, in addition to the vacancy and non use of more than 25% of the commercial areas because of difficulty to perform commercial and public services as efficiently as needed (Cairo Demographic Center 2003).

- Burnt energies: Burnt energies are reflected in two main elements, human being and machine. People who reside in the new cities, especially 6<sup>th</sup> of October and 15<sup>th</sup> of May, are obliged to commute for their work. Most of the labor working in the industrial projects operating in the new cities come from other places. Therefore, movement rates of the means of transportation increase concurrently with the rise in commuters' rates causing an excessive energy consumption, and burden on traffic especially in rush hours. The problems of means of transportation is among the main problems hindering population movement to the new cities because public transportation only runs buses which are not sufficiently available in regular schedules forcing most of the residents to own private cars if they wish to move to those cities (Essam Al – Din 2003).

- Continuous housing crisis and problems of the existing cities: Although minimizing population pressure off the existing cities especially Cairo is an essential objective of creating new cities, however, housing problems grew more complicated. In this regard, the new communities failed to limit the population density reflected in 1450 person per Km<sup>2</sup> in 1990 compared to 1100 person per Km<sup>2</sup> in 1976. In other words, population density rose in the Km<sup>2</sup>



by an average of 25 persons per year during the period of creating new urban communities for the purpose of redistributing the population. New cities also failed in absorbing the immigration trend towards Cairo and Alexandria although most of the new urban communities are located in close proximity to those cities (Nagwa Ibrahim 2007).

- Slow population growth: The overall achievement image of new cities confirm that population growth is lagging behind. In this context, it failed to attain the targeted population. In the first phase of creating new cities – ten years – percentage of permanent residents stopped at 19.6% of the target. As such, total residents in 10 of Ramadan, 6<sup>th</sup> of October, 15 of May, Sadat, and new Borg el A`rab came to 162 thousand whereas the target was 825 thousand. The ratio of resident population to the target in the first phase differs from one new city to another. For example, it reached 100% in 15<sup>th</sup> of May, but only 7% in Sadat, 35% in Borg el A`rab, and 20% in the 10<sup>th</sup> of Ramadan and 6<sup>th</sup> of October. The accelerated growth rate of the 15<sup>th</sup> of May city is attributed to its adjacent location to a major industrial center in Helwan, whereby it became an attraction to huge labor, relative cheap prices of housing, in addition to many facilities provided to the residents compared to other places (National Specialized Councils 1993).

Table (1) below shows the population growth of the main new cities in Egypt. As shown in this table, in 1996, 16 years after constructing the new cities, 15<sup>th</sup> of May continued achieving the targeted population by 100%, Salhia by 90%, however, the percentage was 60% in 10<sup>th</sup> of Ramadan and Sadat, 44% in 6<sup>th</sup> of October, and only 14% in Borg el A`rab. It is observed that 6<sup>th</sup> of October is the most attracting city for residents whereby it scored a growth rate of 15.86% in 1966-2006 due to population settlement and natural increase. It should be noted, though, that the existing industries in the 6<sup>th</sup> of October are less size than those in the 10<sup>th</sup> of Ramadan which scored a growth rate of 10.16% during the same timeframe. In this regard, population size in the 6<sup>th</sup> of October came to 35 thousand in 1996 which rose to 155 thousand in 2006. In other words, it grew by five fold in ten years which entailed increasing the targeted population by 2017 from half a million to million and to 2.5 million for the same year coupled with changing 6<sup>th</sup> of October from a city to a governorate. As for 15<sup>th</sup> of May, it attained the lowest growth during this timeframe whereby it attained 3.3% growth rate, Salhia 8.2%, Sadat 10.08% and Borg el A`rab 10.65%.



**Table (1) The population growth of the main new cities in Egypt**

City	Date of construction	Expected years of development	Expected population (thousand person)	Actual population (thousand persons)		Targeted population (thousand persons)
			1996	1996	2006	2017
10 <sup>th</sup> of Ramadan	1978	20	80	47.833	125.920	500
15 <sup>th</sup> of May	1978	20	65.90	65.560	90.740	250
Sadat	1980	25	30	18.619	48.666	500
6 <sup>th</sup> of October	1980	20	80.40	35.354	154.093	2.500
New Borg el A`rab	1980	20	27.50	4.000	11.320	500
Salhia	1982	20	9.60	8.619	18.957	70

Source: Essam Al-Din (2003) Op.Cit, p 240; <http://www.citypopulation.de/Egypt.html>

- Lack of sufficient attraction elements: The industrial activity serves as main activity of the new cities except for the 6<sup>th</sup> of October which includes as well tourism activity. Specialized studies criticized activities of the industrial sector which lacks a settlement plan for industrial projects or setting up an economic base aiming to provide job opportunities and multiplying the regional income. Studies criticized as well the high capital intensified projects which are concurrently of low labor intensity. (Nawgwa Ibrahim 2007).



Image (1): 6th of October city luxury compounds beside the industrial activities attracting targeted population



Image (2): New Borg el A`rab city achieving to attract only 14% of targeted population after 16 years



Image (3): 10th of Ramadan city scoring a growth rate of 10.16% during 16 years



Image (4): 15th of May city attracting 100% of targeted population

- Failure to implement the original plan: Major changes affected the master plans of new cities creating several activities and usages outside the plans for the interest of groups who influence the decision making. As a result, the proposed growth trend had changed in some cities such as the case in the 6<sup>th</sup> of October, Sadat and New Minia cities whereby some of the agricultural reform areas designated to agricultural associations turned to residential areas due to insufficient water sources such as in Borg el A`rab city (Specialized National Councils).

- New cities' targeted size is Large: The new cities' strategy adopted an approach towards creating large sized cities which in turn placed a huge burden on the State to provide sources for funding infrastructure, services, and housing projects, which according to Stewart (1996) require a long time until it secures full settlement elements and achieve their objective.

- Lack of comprehensive planning of new cities: The new cities had not been constructed based on a comprehensive planning addressing the interrelation between new cities, inter traffic courses on one hand and traffic courses with Cairo on the other as well as the possibility for the new cities to contribute into solving urban problems of the existing cities. In this context, the new cities' policy had been adopted without conducting analytical studies to its socio – economic, environmental and administrative aspects. For example, 2017 Cairo planning is extended north to the borders of the 10<sup>th</sup> of Ramadan city (which is an independent city) whereby it is turned into another suburb of a 16 million people city. This stands as best example for the absence of a comprehensive structural planning. (Specialized National Councils 1993).

### **Policies and mechanisms for creating sustainable cities in Egypt**

- The new cities should be developed in small or medium size with a population of 100-150 thousand that may rise to 250 thousand in exceptional cases in order to avoid funding problems, and accomplish an accelerated settlement. In this regard, small cities are easier in terms of construction, development and management compared to large cities. Furthermore, the new city size should be defined relevant to its nature, function, objective, site, economic



base, relation with the region, and planned job opportunities. However, the anticipated city growth should be taken into account based on the attraction factors and observe diversification of city sizes.

- Ensuring the highest level of independence and self sufficiency to the new city that should be founded on an economic base including income generating activities, maintaining economic balance, achieving comparative advantage, and optimizing its residents' attraction ability such as a major university, industrial zone, tourism activity or others.

- Preparing a feasibility study for the city development project prior to allocating the required investment in addition to taking into account leaving sufficient distance between the new and existing cities in order to avoid construction amalgamation as the case in the new cities close to Cairo that turned into suburbs. It is preferable to develop new cities near middle or small cities that have hinterland in order to meet the services needs of the new cities in the initial phases.

- Developing Egypt's urban development policy on the national level so that to be connected with the socio-economic plans. In addition, it is necessary to observe the comprehensive economic development in the comprehensive national plan of urban development prepared by the Urban Planning Authority. This will allow making structural changes in the distribution of economic activities and housing, while giving priorities to the role of new cities in developing areas associated with national security such as Sinai, and marginalized areas such as Halyeb, Shalateen, Nuba, poor areas in Upper Egypt and developing the Egyptian rural areas.

- Supporting low income housing which would motivate this category to immigrate to new communities. It is expected to achieve community balance, expansion of the consumers' base, providing economic housing subsidized by the State in new cities, streamlining the necessary funding to purchase housing units via credit facilities provided by the State and soft loans.

- Using economic tools for boosting businesses, and economic activities outside Cairo and Alexandria such as imposing taxes on the activities in Greater Cairo, banning to new projects' licensing, and concurrently granting exemptions in the new cities.

- Establishing renewable energy infrastructure in the new cities, using solar energy for desalinating sea water, operationalizing the needed mechanisms, collecting and treating liquid waste, re use treated liquid waste in tree and green belts planting around new cities, rationalization and effective management of water resources, collecting flood and seasonal rain water in addition to improving the management of liquid and solid waste by means of the collecting, treating and re using processes.

- Providing services adequate to all categories, diversified job opportunities sufficient to all categories specially women as an attraction tool to new cities as well as securing socio-economic returns for both the region and State. In addition, creating seasonal cultural and leisure attractive activities.



- Observing the local identity of the new communities as social relations serve as the framework governing community members' interactions, positive situation, stability and adaption of new communities.
- Conducting structural changes in the local administration system aiming to decrease the centralized decision making in Cairo, expanding the competencies and powers of the new city body in order to become first responsible about land planning, preparing and approving new city plans for the central administration.
- Developing partnerships among governmental bodies on the central and local levels on one hand and among civil society organization, private sector companies and NGOs on the other during all phases of new cities planning, implementation and management. This will be done through setting up a board of trustees for the new city comprising representatives of the city residents, labor, investors and municipalities.
- Regular evaluation and monitoring of the new city's performance, revising and updating plans of the urban development according to the performance evaluation and other developments that may take place.

## References

Cairo Demographic Center, 2003, Papers on Egypt's Demography, The Reality of Egypt's New Cities in Terms of Demography, Socially, and Economic (1977-2003).

New Urban Communities Authority, Authority's Achievements 2010.  
<http://www.urban-comm.gov.eg/achievements.asp>

Essam Al-Din, M. A. 2003. "Evaluation of the Egyptian Experiment in Establishing the New Towns in the Desert Areas." *Journal of Engineering Sciences (JES)* 31 (1). Assiut University.

General Authority for Industrial Development, Industrial Zones' Atlas, 2011.  
<http://www.ida.gov.eg/atlas/newcities>

Specialized National Councils: 1993, Report of the National Council of Services and Social Development, 14<sup>th</sup> Round 1993/1994.

Nagwa Ibrahim, 2007, Program of Decentralization and Issues of Municipalities. Center for Public Administration Studies and Consultancies, Cairo University, Faculty of Economics and Political Sciences.

Stewart, Dona J. 1996. "Cities in the Desert: The Egyptian New-town Program." *Annals of the Association of American Geographers* 86 (3).

## **Indicators of urban sustainability for a model of change.**

**The Ecological Urban Interaction Matrix (MIEU): a methodology –based on bio-construction- to plan the quality of life and the environment of urban settlements.**

**Author: Pàmols, David;** architect MSc. Master Bio-construction.University of Lleida (UdL) – Lleida (Spain)

***Abstract:** The city as biophysical matrix maintains relationships with its geographical location. These express themselves through ecological and anthropogenic processes at different spatial and temporal scales, where there exist interrelationships capable of being modified reciprocally. The current city demonstrates in its settlement patterns configuration, uses of soil and activities, expressed as diverse ecological landscapes within a heterogeneous, fragmented and multiple mosaic that is comprised. But is it our analytical approach, using current urban indicators, holistic enough to deal with this complexity?*

*The purpose of this paper is to promote discussion on three aspects that are being studied for many teams across Europe. The first one addresses the methodology of approach to the problem, comparing the analytical model: pressure, state, response, with the analytical - theoretical model: system – environment. The second one shows, under the theoretical prism system – environment model, a proposed methodology – MIEU: Ecological Urban Interaction Matrix - and proposes a set of models and basic indicators of the city and its metabolism and defends a more complex approach to the problem of social planning of urban settlements. Finally, some indicators of human appropriation of natural resources from the bio-construction favoring a more holistic view to the discussion, from the perspective of subjectivity; the concept of quality of life and the analysis of the sustainability of our frames of social relationship.*

*In short, this way of making the city incorporates the proposed methodology, based on a comprehensive vision, the values that enable sustainability, socially equitable and environmentally balanced energy efficient urban planning.*

**Keywords:** *indicator, planning, sustainable development, bio-construction, urban*

### **Basic indicators for urban sustainability planning**

We are aware that the process or path to urban sustainability demands a collective raising awareness and concrete action on the part of the administration. To channel these actions there arise initiatives of urban management and planning. The conceptual imprecision associated with the paradigm of the sustainability must not be an obstacle for the creation of indicators that, in this case, must be a result of a creative local process that overcomes problems and conflicts. It is imperative to choose meaningful indicators for the aims proposed in each case and then to establish a parallel action plan or an effective performance that allows improving progressively the results of the indicators in order that the city is sustainable. Without a change of mentality in people with facts such as recycling, reuse, civility, mutual respect, etc. the results will not be more favorable to the sustainability. Also it is necessary to establish priorities, that is to say, to know in what situation we are to decide where to start.

The aim of our study is to provide a methodology for searching and selecting the most appropriate indicators in each case for sustainable development and analyze how sustainable development can and must be planned and based on clear and precise actions for a place or a context . These actions must be binding, which is possible only through planning.



### **The usefulness of indicators**

An indicator must be clear, understandable, trustworthy and, in the planning, should help to meet targets for improvement. Indicators should respond to identified needs or problems or just intuit to elaborate on them, limit them and be able to find solutions. Indicators, providing information about the current state of resources, intensity and direction of possible changes, can help consensus among citizens reality of sustainable development or its absence in a locality and orientate the formulation of policies so that they propose concrete actions that are going to have acceptance among the citizens. Do we assess sustainability techniques and methods for the sustainable use, for its conservation and restoration or are we stating the unsustainability of the model of existing development without proposing effective and binding solutions? Might it be the unsustainability of the development a major motivation than the search of the sustainability? Or it will be furthermore to see how our health cracks unless we change many of the daily habits? What specific indicators to be adopted then?

### **Basic concepts on indicators**

Definitively, the indicator is a measure of the observable part of a phenomenon that can assess other unobservable portion of the phenomenon (Chevalier et al.,1992). The indicator must allow a succinct, understandable and scientifically valid reading of the phenomenon under study. In this sense, the approach of Gallopín (1996) turns out to be more interesting from the optics of the Theory of Systems on having defined the indicators as variables (and not as values), that is to say, operative representations of an attribute (quality, characteristic, property) of a system. The indicators are therefore images of an attribute, which are defined in terms of a measurement procedure or particular observation. Each variable can be associated with a set of values or states through which it demonstrates.

### **Considerations on the current systems of environmental indicators**

Departing from an initial<sup>1</sup> model of the reality under analysis based on the Theory of Systems, a system of indicators provides an analytical instrument to represent that so comprehensive instrument and track variables based on the degree to which specified target levels. In the area of environmental policy, in particular on information about the state of the environment, a considerable summit has been produced in the use of indicators, called strictly environmental.

### **The inclusion of indicators in common analytical structures: the model pressure-state-response (P-S-R)**

Today, the dominant framework of analysis is called Pressure-State-Response, first developed by Frien and Rapport (1979). This framework, introduced strongly in the set of countries of the OECD , as having constituted the model of development of environmental indicators of this international organization, is based on the concept of causality "human activities exert pressures on the environment and change their quality and the amount of natural resources." Society responds to these changes through environmental, economic and sectoral policies. The utility of this model that anyone adapts to the steps of a decision-making model and that any decision on the other hand, it is common to the way of thinking about whom they decide and about the scientific community.

<sup>1</sup> As recalled in most studies on the topic (MMA, 1996), if the scientific model a priori is not coherent and consistent, the system of indicators will not be trustworthy.

The demand for clear, simple and added to the description of a problem to decide faces information on this model with the absence of an appropriate theoretical framework, making it difficult to discern between different information without any theoretical hierarchy. Faced to such a lack, one chooses in many occasions to integrate a large number of variables in the system, for fear of leaving significant variables out, returning to the starting point: a huge amount of data that do not transmit the necessary information to make decisions.

### **The inclusion of urban indicators in integrative theoretical models: the model system-environment**

All individual systems and ecosystems in nature have a tendency to increase complexity in the time. Indeed the evolution of species and succession in ecosystems show a path of successive organizations whose trend is the increase of its complexity. A trend that gets onto the next step so as to better control the environment variables and ensure a better future. The "control" of environment variables supposes the capacity of anticipation that has the system to get accommodated to the messages in the shape of materials, energetic and information flows that environment sends (the environment is also a system). A deeper analysis allows us to identify the variables with a minor flexibility and therefore the indicators that might be established to do a follow-up of the unit SYSTEM – ENVIRONMENT trends in its future projection.

### **Some issues for discussion**

Is the P-S-R analytical model the right one for the development of urban indicators? System-environment model is a model with theoretical content enough for the diagnosis, planning and monitoring of urban management models? Is it a calculation instrument interesting and viable enough? Does it make sense to establish indicators without having proposed a plan or program on the question that is meant? Without a management model that framed, indicators make sense? Urban indicators to go to where? Indicators should be participated and agreed with civil society? Is it possible to compete with an information-based strategy and not in the consumption of resources one: land, materials, and energy? Are processes towards the sustainability incompatible with the current economic logic?

### **MIEU: Urban Ecological Interaction Matrix. An indicators methodology for a model of change.**

After the foregoing analysis, the set of indicators proposed are incardinated in each of the axes of the compact mediterranean city model in which the morphology and functionality of the system is evaluated. The model of complex city that it aims to measure the urban organization, the efficient city that seeks to ascertain the degree of consumption of resources and the efficiency thereof and finally the city socially stable model aims among other know things social cohesion proposed in planning processes and planning of our cities.

### **Evolution of the concept: quality of life**

At first, the term Quality of Life appears in public debates concerning the environment and the deteriorating urban living conditions. The term began to be defined as an integrating concept that encompasses all areas of life (multidimensional character) and refers both to objective conditions and to subjective components. To avoid this confusion is suitable to

distinguish between needs (determined by human nature purposes) and satisfiers (culturally determined means).

### **Incorporation of subjectivity**

The social character of subjectivity is one of the axes of reflection on the concrete human being. Preferences are defined in the realm of the subjective-particularly, are a competence of each person, and do not threaten, therefore, the suppositions of rationality of the market. Concerning, instead, to fundamental human needs requires from heading placed in the plane of the subjective-universal, which turns sterile any mechanistic approach. The analysis of the human needs can never be considered to be a closed and finished product, and that in any case, must be judged by the own interested persons; multidimensionality can not cloud the other inalienable aspect of quality of life: **subjectivity**.

### **Village vs. urbanization**

The methodology set out on this issue (MIEU), bet for the city (village), not for the urbanization: the urban minimal phrase from which to build the development of urban settlements, from a necessarily holistic and complex approach, based on the compact Mediterranean city model and with a dimensional identical approach to energy sustainability, social relations of its members and that allows personal development from public space and the meeting of complementaries. That is the scale of the village. And this introduces for its own approach, SUBJECTIVITY as the necessary ingredient for the development of urban indicators.

### **Social relationship frameworks sustainability**

It is more plausible to consider that economic development is a modification of the technological and social context that causes a change, not of the needs, but of the most urgent lacks and of the most accessible means to face them. The economic development changes, certainly, available satisfiers and its effective use, which has implications in satisfaction of the diverse needs. Under this perspective we should be comparing the subjective satisfaction in different cultures and evaluate the suitability of the specific satisfiers.

### **Quality of Life and sustainability**

The measurement of quality, as we know, turns out to be an almost impossible task by our proper ignorance of human nature, which also applies to the measurement of social costs; nevertheless, for the environmental costs one relies on slightly more precise derivative instruments of knowledge of the physical sciences.

### **Methodology proposed**

It has been a question of establishing a methodology to help to look for solutions to the environmental problems from a holistic perspective. This methodology allows us to define or establish a series of criteria to select indicators (some already suggested by the legislation) that may lead to concrete actions. Citizen participation must be present throughout the process and start with the most significant indicators and a systematic follow-up does not exclude going expanding over time to analyze indicators. These measures must be gathered in the planning.

### **The interaction matrix**

The factors and the natural environment variables interact with each other, so it is difficult to establish a clear boundary between them. However, due to this fact they can relate the variables that a priori are involved in the growth and genesis of an urban settlement. With this intention, the methodology incorporates the main factors of interaction between the Natural Environment and the Urban Environment and their interaction with the environment is evaluated. The relationship among the natural and urban environment can be summarized as an interaction matrix or counterfoil, a Cartesian box with environment variables on the horizontal axis and the urban environment in the vertical one. The cells are completed with a detailed list, existing in turn empty cells when such a interaction does not take place.

### **Environmental optimization criteria**

To realize a few Environmental Optimization Criteria on a settlement, the methodology proposes to evaluate, in detail, almost all the aspects that determine this interrelationship. A matrix to interrelate these aspects, in order to be able to numerically gauge their impact on the design of the settlement is established for that purpose. (These and other indicators tracking model are presented in an extended document analysis)

### **Implementation of the methodology MIEU**

The methodology of the Urban Ecological Interaction Matrix is implemented from a series of simple resources, based on the open-source culture, allowing easy and efficient management adjusted to all available resources and situations. It uses well-known, public and accessible to the general public technologies and allows the critical edition of results on a simple, fast and effective way, but at the same time complex and holistic.

It is developed on the basis of five (5) stages of development and consecutively interrelated.

- I. ***Needs and satisfactors.*** *Survey of needs among users (or potential users).* A survey of 10 items will be performed, rating from 1 to 5, among actual or potential future users, on the social, economic and environmental aspects of the interaction matrix.
- II. ***Indicators.*** *Rating certain environmental variables (planner).* The planner might value from 1 to 5 the suitability of the compliance of the design respect to the interaction matrix, on about 75 factors, and for each of the 5 environmental optimization criteria boxes.
- III. ***QFD Analysis.*** *Needs and satisfiers function deployment.* QFD (Quality Function Development) is a method of quality management based on transforming user demands into design quality, to deploy the functions that provide higher quality, and implement methods to achieve design quality into subsystems and components, and ultimately to specific elements of the manufacturing process. The MIEU methodology proposes an analogy in using this system of quality management for existing or planned urban settlements. So it proposes the incorporation of data derived from the survey among users as *client's demands* and the analysis of the environmental parameters from the interaction matrix as the aspects of the *manufacturing process* of the new settlement.

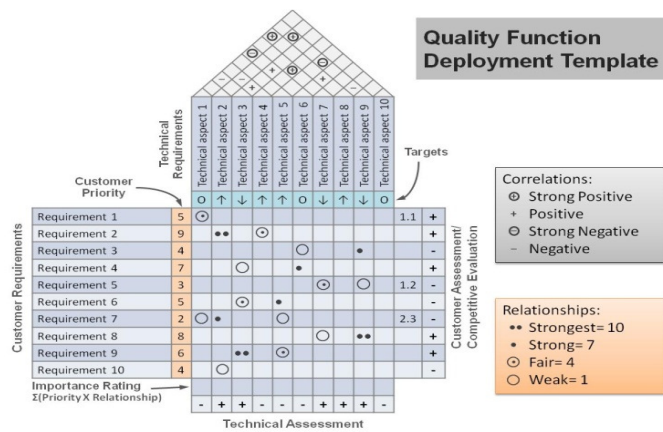


Image 1: Functional diagram of the QFD analysis and interrelationships

IV. **Radar charts.** Graphical analysis of results. From the weighting obtained in the QFD analysis for the planned settlement, the data are entered into a spreadsheet that compares the items obtained with those would arise in such an ideal situation (needs and satisfactors above the QFD analysis and optimal results obtained through the environmental interaction matrix rating).

V. **Conclusions and assessment.** Analysis of results and comparison with the "ideal" scenario. From the introduction of the data in the radar chart, it is possible to proceed to the critical analysis of the scenes obtained and their attachment to those raised in the ideal scenario. On this one, the necessary alterations are established to improve the planning, until the chart throws the closest to desirable results, which allows to work corrective aspects on the model, to improve it

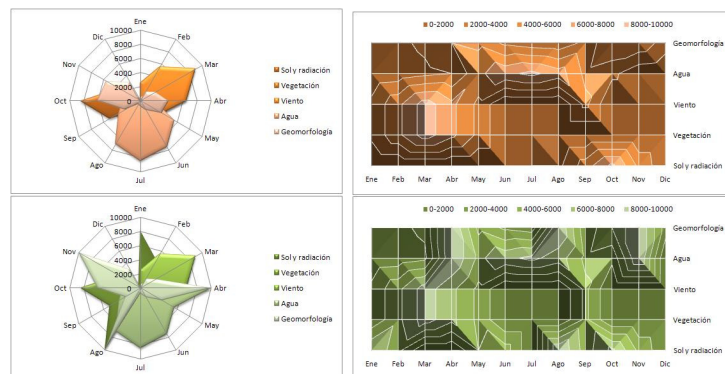


Image 2: Radar charts for a comparative analysis of results

### From the point of view of the bio-construction

For everything previously developed, especially as regards the introduction of subjectivity, the needs and the satisfactors in which there is fitted the methodology of Urban Ecological Interaction Matrix (MIEU), this can only be developed successfully under the contribution of bio-construction point of view because it is a way of building and designing the cities so they adjust to parameters of environmental and social sustainability, guaranteeing mobility, the energetic efficiency and livability **both real and perceived**. Bioconstruction is a way to build and plan cities incorporating criteria and techniques for ensuring environmentally friendly healthier, final result, with the use of neither non-polluting nor toxic, reusable and recyclable



materials, with solutions to save energy use and preference for renewable energies. Buildings constructed under this system have a high degree of functionality with mechanisms for capturing energy (as for example solar panels), recycling and water saving and to the most suitable treatment of residues. As a concept of urban development design of streets and public spaces looking mainly a distribution of buildings that could take advantage from natural energies (sunlight, natural ventilation, energetic potentials of the soil ...). Thus, the space around the buildings reaches a higher level of real and subjective habitability. It is no longer a strange statement for anyone recognizing that the quality of life, as perceived by people, has much to do with the environmental characteristics of their urban environment.

## Conclusions

A system of indicators demands a systematical follow-up with continuity in time, what could be done to systematically include in the planning an annual external audit, for example. An excessive number of indicators does not turn out to be operative, so(then,since) in this case the follow-up and control of the environmental performances would not be practical and manageable. It is important to prioritize and summarize the indicators: its interesting them to be a few but significant and to create and promote a true culture of sustainability that passes through a deep environmental education leading to concrete actions. In that sense we have tried to demonstrate with the MIEU methodology the importance of actions that promote sustainability are binding on the population, which is only possible through planning and citizen participation. The specific actions that enable sustainable development constitute the purpose of the raised methodology. These actions can plan them only through a proper selection of indicators and a change in the paradigm of perception of the indicators used for the design and analysis of urban settlements. If the real purpose of the indicator is intended to facilitate the identification of problems for their possible solution, any simplification of it turns out counterproductive, while controversial, since the mathematical mechanisms, however sophisticated they may be, only serve to disguise the arbitrariness of the design.

## Final corollary

The experiences analyzed have served us to see that the proposed methodology should be used to rank the most problematic aspects of the analysis of urban planning in relation to sustainability in terms of their severity and towards concrete actions involving alternative solutions planning so that these actions are binding and are agreed upon by the population to assure its viability and effectiveness. For all this it is necessary to introduce a more holistic vision of the analysis wich incorporates the analytic subjectivity as aspect of critical appraisal and that falls, in equal measure, in environmental aspects, the socio-economic ones but also in those who pursue the satisfaction of people with their environment, in what has come to be theorized as the 'Quality of Life'.

It is very important to collect as binding planning clear outcomes and objectives that relate to sustainability and the need to be continuously implemented. Otherwise, it will continue being an object of debate and good intentions without reaching any effective result that supposes an improvement.



## **A New Energy Model for Madrid: ‘Urban Nanoclimates’**

### **Speakers:**

Carmona Casado; Juan Carlos

Camilo José Cela University, Madrid, Spain.

**Abstract:** *This research work is aimed at making evident the significant gradient of temperature (up to 6 °C) at street level within the same urban environment (not larger of 2 Km in length) and with measurements taken at the same hour, day and month of the year. Energy savings will be quantified by producing a more reliable climate database at the level of an urban block, thus introducing the new concept of “Urban Nanoclimate” to produce more accurate environmental simulations.*

*These temperature gradients on building external conditions, for the same urban environment, make possible to propose a new alternative by describing in detail the regulation in force. This may lead to a saving model not considered so far, but very useful from an energy viewpoint.*

**Keywords:** *Urban Nanoclimate, saving, energy model, efficiency*

### **State of the Art**

*“If we are aware of the existence of microclimates inside microclimates in an urban environment at the scale of a neighborhood or block, we generate a much more effective description of the climate reality than the one established in the regulation in force of the Building Technical Code. We will change then the prefix and rename the new situation as “Urban Nanoclimates”. Just think about the meaning of this (...)” (1)*

This discourse awakened inside me an arduous interest in first-hand knowing and showing the existence of these “Nanoclimates”, and more specifically in quantifying the Energy Saving that the assumption of its existence would provide to our architecture. The theoretical framework was indisputable: “Heat Island” effect (2), very general climate databases based on measurements from weather stations fixed in places far away from the city and one another, very general Technical Regulations based on previous data, range of analysis constrained to a city scale ...

A first approach, thermometer in hand, took us to analyze the physical and architectonic environment of Alcalá Street, Madrid. More specifically, a stretch of this street going from Cibeles Square (around number 20) to its intersection with Arturo Soria Street (around number 414). This first touchdown was highly revealing, to the point of being able to see firsthand, differences amounting up to 4 °C among different measurement points. This first



evidence opened a precise path towards a new conception of energy consumption in buildings: we could quantify reliable differences among the thermal charges of buildings in terms of the demand according to the current and general regulation and weather data and those that can be postulated from a new existent physical situation.

We are well aware that this is a first step towards a new conception of energy saving. The climate data used in the current regulation address “clino” periods, weighted mean of the data obtained within the last 30 years, while our study is based on measurements obtained in a single year. Because of this, we shall specify that it is not a matter of generating a new database, but of stressing and quantifying in percentage and economic terms the new discovered architectonic reality. The new temperature values are not so important as the “differences” or “increments” among them.

Once the matters of study within a given urban environment are determined, we shall extract from the databases generated the corresponding values of temperature, relative humidity, wind speed and atmospheric pressure (3). Among these values, the first ones are those truly meaningful regarding a quantification of the real temperature increase, unconsidered by the Measurement Integral System (SIM) that the Honourable Ayuntamiento de Madrid has established in the city, but in our opinion at a larger scale than that suggested in our hypothesis.

Additional data of relative humidity, wind speed and barometric pressure will be used as reliable signatures justifying temperature increments in our chosen physical environment.

### **Antecedents**

The existing studies on urban climate have mainly focused on confirming the existence of a temperature gradient in favor of the downtown, between the latter and the city suburbs.

The first study is relatively early and was verified in London (Howard, 1818). Ulterior studies in Paris and Vienna corroborated the same phenomenon, which was called a “heat urban island” by Manley in 1958. It was readily noticed that a temperature difference is associated with a humidity difference, in inverse order.

The discovery of this double climate phenomenon, together with the publication of the former general works on urban climate, as well as the international symposium on urban climates in 1968, sponsored by the WMO (WMO, 1970), motivated the research on local basis urban climatology, mainly focused on the acknowledgement of the heat island in different cities, these studies being of a relatively easy methodology.



Nowadays it can be said that most of world metropolis count on climatic studies at two level analysis. One of them, preliminary, with an essentially approximate and descriptive nature; in the other, more recent and deeper, urban climate is analyzed in its complexity, with climatic and urban implications, and where the concept of microclimate is developed.

With respect to the methodology, we know that in order to clearly determine the existence of microclimate differences within the city it is not enough dealing with observations coming from usual weather stations, since their main scope is very different regarding the spatial scale and, therefore, their data cannot be taken as a reference. Hence it is necessary to carry out a direct observation of the climate elements by means of systematically making meteorological measures on the ground.

This procedure, very usual at present, constituted a decisive advance in the study of the city climate, apparently first used by Schmidt in 1930 in Vienna, introducing a new technique that has been revealed along these years to be a very useful and efficient tool to study the temperature differences observed within the cities.

In Spain all these studies have been rather scarce. Researchers from the CSIC, in Madrid, have tried to cover the gap with a preliminary pioneering publication (López Gómez, 1988). Later on, some analogous investigations have also been carried out in other Spanish cities, such as Barcelona (C. Carreras, M. Marin, J. Martin Vide, M. Moreno, J. Sabí, 1990), Logroño (Ortigosa Izquierdo, Sobrón García, Gomez Villar, 1998), Madrid (ESA, Universidad de Valencia, Universidades Autónoma and Complutense de Madrid, Universidad de Vigo, CIEMAT, AEMET, CECAF, 2008), Bilbao (Tecnalia, Universidad de Kassel (Alemania), 2011).

The work here presented is inserted into the same effort, but it also intends to give a stroke of rigor so that from the results obtained it will begin a reflection on the implications of including '*nanoclimate*' conditions in Town Planning Regulations and/or Energy Efficiency. As already discussed, London was the first one in attracting attention of this type of research since the beginning of the XIXth century (Howard, 1818), becoming a paradigm of the heat island phenomenon (Chandler, 1961) and the studies on urban microclimate (Chandler, 1965). Nonetheless, in recent years pioneering studies funded by European funds have been carried out in some North-Western cities, such as the cities of Rotterdam and Arnhem (Netherlands) and Athens (Greece) (Future Cities Programme; University of Wageningen (Netherlands) ..., with the objective that their results will be taken into account to improve the town planning, and to develop standards and urban design tools. New York City has a preliminary study about the heat island (Bornstein, 1968). Obviously, Tokyo is among the more studied Japanese cities, with many works on urban microclimate (Kayane, 1964; Sasakura, 1965; Nishizawa,

1979). In Latin America, Mexico City (Jáuregui, 1973), Rio de Janeiro (Gallego, 1972) and especially Sao Paulo with a thesis constructed from information taken from satellite pictures (Lombardo, 1985) are worth mentioning.

Regarding the inclusion of the results obtained from the various existing investigations carried out worldwide, as mentioned above, into the Town Planning and/or Temperature Regulations or of Energy Efficiency, it follows that issues on climatic zoning within a city or a province have not been taken into account, but the existing classifications are much wider, usually covering regions, cities, or even boroughs in the most rigorous ones. In the United States of America, the ASHRAE Standards; in Latin America, we highlight the Normativa Térmica de Argentina (IRAM); in Europe, it is worth mentioning, for example, the French *Réglementation Thermique* (TR) and, of course, our Código Técnico de la Edificación

### Environment of study



Figure 1: Google Earth study environment

Within the urban fabric of Madrid we choose one of its most representative streets as working area, in particular, a stretch of 5,332.98 m, East-West oriented, between its intersections with Recoletos promenade, at Cibeles Square (Point 1), and Arturo Soria Street, more East.

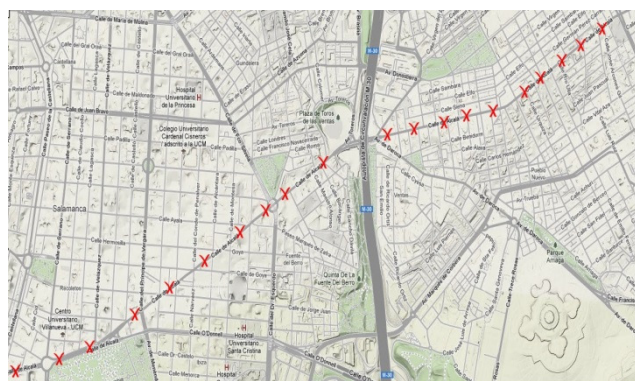


Figure 2: Google Earth study environment





It seems reasonable to establish a “grid” of measurement points along a rectilinear path with a maximum distance of 250 m between consecutive points. In this way a table is generated, which will be able to verify variations of up to half a Celsius degree in relatively short distances within the urban scale that we are considering.

It is also intended to establish a clear difference between sidewalks “in the shade” and under the action of solar radiation. Because of this, two simultaneous measurements for each sidewalk are carried out in order to remove the possibility of needing a weighted mean of the results by taking a single daily measure. In the case of two measurements, a single sidewalk could have been considered to generate the daily mean values necessary to work and to carry out the corresponding energy calculations.

Similarly all those aspects of the urban morphology that may affect the recorded temperature differences will be analyzed, to take them into account when generating any kind of respective conclusion: vegetation or its absence, pavement class, degree of traffic at the street, width, users, finish colors of the façade materials and street furniture (incidents in the albedo)... We therefore have a solid basis to support our investigation regarding the proposal of a new concept to understand ‘Energy Savings’, such as it is suggested by the European guidelines in this matter.

The supervised field work, regarding physical measures, corresponds to an anual planning, with a minimum of two weekly measurements, on alternate days, and at the same solar time. To make the students’ work easier concerning availability, no measurement will be taken over the weekend (less user traffic than usual in the street), nor in consecutive days in order to establish feasible differences in the performed measurements.

### **Calculation method**

Once the climate database to be used is set, we shall establish a “standard” virtual model to compute the different heating and refrigerating (in the wintertime and summertime, respectively), and ventilation (in both seasons) demands according to different positions of such a model within the chosen urban environment. The difference between the results obtained will allow us to quantify the saving percentage that we can suggest, following this new methodology, and with respect to the reference values currently accepted.

Figure 3: data-collection card model



Therefore, any energy difference will be understood as a saving, since the design to be considered in the architecture that addresses the needs of that plot of the urban grid will be affected by these new computed values, much closer to the existing physical reality.

TRABAJO DE CAMPO		TOMA DE DATOS CLIMATOLOGICOS C/ ALCALÁ - MADRID					A01
MES	SEPTIEMBRE 2013						40º 25' 59" N 3º 38' 57" O
DIA	TEMPERATURA (°C)	HUMEDAD RELATIVA (%)	VELOCIDAD VIENTO (m/s)	PRESIÓN ATMOSF. (kPa)	MED TEMP Hº		
3	23,80	48,20	0,80	93,98	20,50		
5	24,10	49,70	0,70	93,96	20,50		
10	22,90	44,10	0,40	94,40	20,50		
12	17,80	48,70	0,50	94,39	20,50		
17	23,60	46,00	0,00	93,52	20,50		
19	24,50	38,10	0,00	93,87	20,50		
24	25,10	39,60	0,30	93,61	20,50		
26	24,30	39,80	0,00	93,56	20,50		
MEDIA	23,26	44,28	0,34	93,91	20,50		
COTA							687,77

Field measurement model

Measurement tables will be thus generated for each month of the year at each point of study, with the purpose of establishing weighted monthly means during the most unfavorable simulation periods (winter and summer).

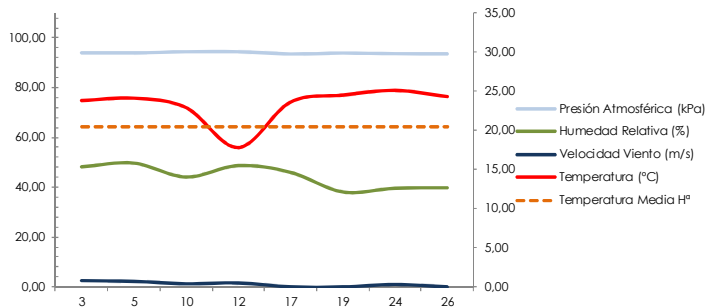


Figure 3: data-collection card model

Choice of the architectonic model to be simulated

Within the study environment, we have a wide range of typologies, building systems and singular buildings that can properly define Madrid’s architectonic environment in a given period. It is precisely because of this that the choice of one model or another is not that important, but keeping the particular choice and choose, apart from the real position, other virtual locations of plots with the purpose of being able to simulate the weather conditions measured in the field work. In this way, we will be able to make evident the different thermal charges (and, consequently, different energy demands) that are generated from new external conditions. We will try to make evident that within the same urban environment, even at the scale of a neighborhood or a block, there are (positive and negative) increments of temperature with respect to the temperature mean value out of the city, the latter being used in any energy calculation (this reference mean value comes from the closest weather station, namely Retiro, in our case). We shall thus focus in increments and not in given values of temperature to reproduce the virtual conditions for the same model in different environments. In this way, the measurement scale will always be the same and we will be able to conclude why we can detect such differences.

After the previous assumptions, we decided to consider a characteristic model for living block, in principle framed in time around half the urban life of the axis of Alcalá Street, corresponding to an architectonic typology of closed block, dwelling row house, with main façade and a service inner yard with two side bays housing dwellings. The year of construction of the chosen dwelling block is 1955, a decisive year for Madrid's urban history, which coincides with the construction of social housing neighborhoods and supervised villages in the city (Hortaleza, Canillas, ...). Our study model will then be a reference building with the same typology to the one located in 308 Alcalá Street.

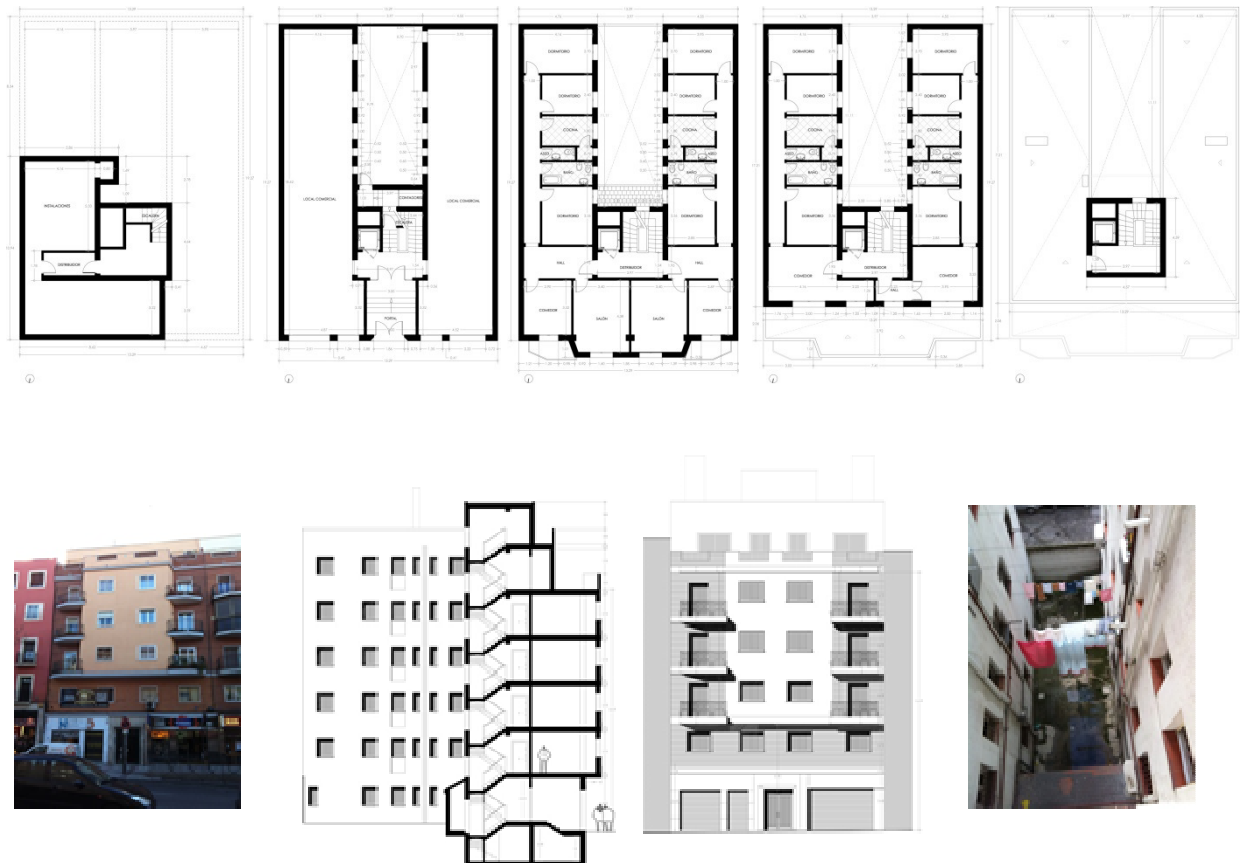


Figure 4: Planimetry and views of the reference building in 308 Alcalá Street

## Conclusions



COMPARACIÓN ENERGÉTICA DE PUNTOS DE SIMULACIÓN																
	A1		A2		B1		B2		C1		C2		$\Delta P$		%	
CARGAS (W)	REFRIG.	CALEF.	REFRIG.	CALEF.	REFRIG.	CALEF.	REFRIG.	CALEF.	REFRIG.	CALEF.	REFRIG.	CALEF.	REFRIG.	CALEF.	REFRIG.	CALEF.
PLANTA SÓTANO	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
PLANTA BAJA	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
PLANTA 1	5.955,11	14.469,44	3.178,89	8.244,09	5.004,40	13.380,81	4.840,48	12.762,01	6.088,36	13.208,16	5.709,85	12.889,86	2.909,47	6.225,35	1,92	1,76
PLANTA 2	6.451,20	13.460,45	3.671,72	11.274,12	5.393,65	12.478,11	5.290,54	11.922,78	6.058,17	12.322,69	6.160,74	12.037,90	2.779,48	2.186,33	1,76	1,19
PLANTA 3	6.762,72	11.639,75	3.847,70	9.907,80	5.543,17	10.847,22	5.399,76	9.772,10	6.618,13	10.722,94	5.830,98	10.510,78	2.915,02	1.867,65	1,76	1,19
PLANTA 4	7.269,86	14.364,72	3.392,88	11.958,41	6.232,06	13.289,02	6.047,90	12.674,35	7.528,00	13.118,32	7.149,56	12.800,74	4.135,12	2.406,31	2,22	1,20
PLANTA ATICO	8.197,99	16.495,02	4.907,11	13.508,96	7.024,21	15.172,34	6.090,68	14.398,54	8.169,39	14.961,46	6.712,42	14.554,46	3.290,88	2.986,06	1,67	1,22
TOTAL EDIFICIO	34636,88	70429,38	18998,3	54893,38	29197,49	65167,5	27669,36	61529,78	34462,05	64333,57	31563,55	62793,74	15.638,58	15.536,00	9,32	6,56

COMPARACIÓN ENERGÉTICA DE PUNTOS DE SIMULACIÓN				
	$\Delta P$		%	
CARGAS (W)	REFRIG.	CALEF.	REFRIG.	CALEF.
PLANTA SÓTANO	0,00	0,00	0,00	0,00
PLANTA BAJA	0,00	0,00	0,00	0,00
PLANTA 1	2.909,47	6.225,35	1,92	1,76
PLANTA 2	2.779,48	2.186,33	1,76	1,19
PLANTA 3	2.915,02	1.867,65	1,76	1,19
PLANTA 4	4.135,12	2.406,31	2,22	1,20
PLANTA ATICO	3.290,88	2.986,06	1,67	1,22
TOTAL EDIFICIO	15.638,58	15.536,00	9,32	6,56

From the results obtained, we corroborate that according to the position of the building within the same urban environment, due to the influence of a series of factors here analyzed (new climate database, orientation, sun exposure, shades, ...) we may obtain a difference of up to 9.32% concerning refrigeration charges and up to 6.56% for the heating ones. Other factors such as traffic, materials, vegetation, use, ... will be decisive to climatology classify each part of the city.

A difference of up to 10% in energy demand per dwelling implies a remarkable economical saving when going up in the urban scale (building-block-borough-city). Because of this, we shall always advocate for an institutional and political turn towards this path by only redefining the existing legal framework: “we may become efficient in Architecture without making Architecture”.

## References:

- (1) Excerpt from master class given by D. José Miguel de Prada Poole in his course on “Análisis de Proyectos Paradigmáticos”, within the Master in Energy Efficiency and Bioclimatic Architecture, at Universidad Camilo José Cela. July 2011
- (2) Antonio López Gómez, Julia López Gómez, Felipe Fernández García, Antonio Moreno Jiménez. El clima urbano. Teledetección de la isla de calor en Madrid. Ministerio de Obras Públicas y Transportes. 1993.

## **Methodology for Urban Comfort Management using Geo-Referenced Computer Applications**

**Authors:** Ortega Gozalo, D; Navarro Monreal, J; Sertutxa Moriano, A; Hernandez Minguillón, R; Irulegi Garmendia, O.

*Quality of life in architecture – Department of Architecture UPV/EHU, Donosti, Spain*

**Abstract:** *There are many factors that determine the perception of comfort for people wherever they are. Throughout the last century different models of comfort have been developed, which integrate different parameters in order to characterize the external environment. The most accepted models consider both objective (environmental conditions or physical characteristics of the people) and subjective (feelings of individuals) parameters.*

*Contrary to what happens in indoor environments, the main difficulty in assessing the degree of comfort in an outdoor environment lies in the precision and control of data collection, since commonly used generic databases are not representative for small time periods.*

*Technological development and the introduction of GIS systems in daily life increasingly facilitate citizen interaction with society. They are presented as a useful integration tool and a potential source of a greater field of action. GIS tools in research studies are becoming more common, although there are few oriented towards new methods of work arising from the integration of geo-reference systems and social interaction in the study of urban comfort. A new methodology for comfort management in outdoor environments enables data collection increasing, their classification, the characterization of a model of comfort and appropriate improvement strategies. The methodology, by using GIS, achieves a greater understanding of the factors that quantify urban comfort enabling more appropriate improvement strategies.*

**Urban confort, confort index, GIS, Physiological Equivalent Temperature.**

### **Introduction**

Subject: New technologies and the incorporation of geo-referenced systems in our daily life allow more social interaction. They are a growing source of information and knowledge transfer, and therefore, a potential research tool in many fields, such as the study of comfort in outdoor environments. The aim of this study is to optimize the new technology facilities and GIS capabilities to reach a more real knowledge of the parameters involved in comfort in outdoor environments, in order to enable a better management of enhancement of such comfort.

Concepts of comfort: A general definition of thermal comfort may correspond to the neutral feeling that an individual experiences in a given thermal environment.

Even if the interest in understanding and knowing the factors involved and how they relate is not new, research studies have increased exponentially in the last century. As a result, numerous models and comfort indices (aimed at integrating in a single value the effect that various basic environmental parameters have on the sense of physical well-being) have been established. Research studies on this topic have been developed from different perspectives:





physiological, psychological, climatological, biometeorological, etc. The distinction of three groups of indices is accepted [1], [2] in order to classify the different comfort models:

**Empirical or Synthetic Indices:** Based on the premise that, with the same environmental conditions, the same physiological strain occurs, without evaluating the role that individual characteristics of human physiology has.

**Analytical or Rational Indices:** Based on the heat balance of the human body. In addition, they integrate physiological parameters (such as temperature and moisture of the skin), behavioral parameters (metabolic rate due to the activity and the thermal resistance of clothing) and environmental parameters (air temperature, mean radiant temperature, relative humidity or air velocity).

**Direct Indices:** Exclusively based on the measurement of physical parameters characterizing thermal environment, without considering the physiological effects that environmental conditions have on people.

**Comfort model selection:** Physiological Equivalent Temperature (PET) is a model widely used in research [3], [4], and supports the use of GIS applications. It is based solely on four environmental indices (air temperature, relative humidity, wind speed and mean radiant temperature). The comfort rating scale does not require exact calculation precision and the final result, a temperature in Celsius degrees, is easily interpretable worldwide as a comfortable, warm or cold environment. Although the PET index is based on the heat balance of the human body as Höppe had shown, the incidence of metabolic activity and clothing values of those who are in space study did not produce significant changes in the final result of PET, so it is not necessary to include this information to the studio and thus data collection is simplified.

Numerous studies have also shown the importance of subjective aspects such as cultural and psychological on thermal comfort. The rating scale for a model of comfort is not equally valid for everyone so it needs to be calibrated in each different place on earth.

### **Methodology for Urban Comfort Management using GIS**

**Methodological framework:** Working with georeferencing tools will allow a more realistic and updated knowledge of the information. In this case, referring to comfort in outdoor environment, it must enable the development of more accurate analysis models which will be better calibrated to the particular conditions of each place and its inhabitants. The growing participation of individuals in society through technology used daily and the transmission of information, facilitate broadening of the areas of study and further deepening of the investigation.

A management model arises on the premise of simplicity of information, both in data collection or calculation, and in the results. Thus, the whole process can be disseminated and understood by all individuals. Another important aspect is the need to raise a flexible methodology that allows to incorporate new variables in the future. The overall scheme of

work on the proposed model (Figure 1), is divided into four phases: data collection, storage, analysis and results.

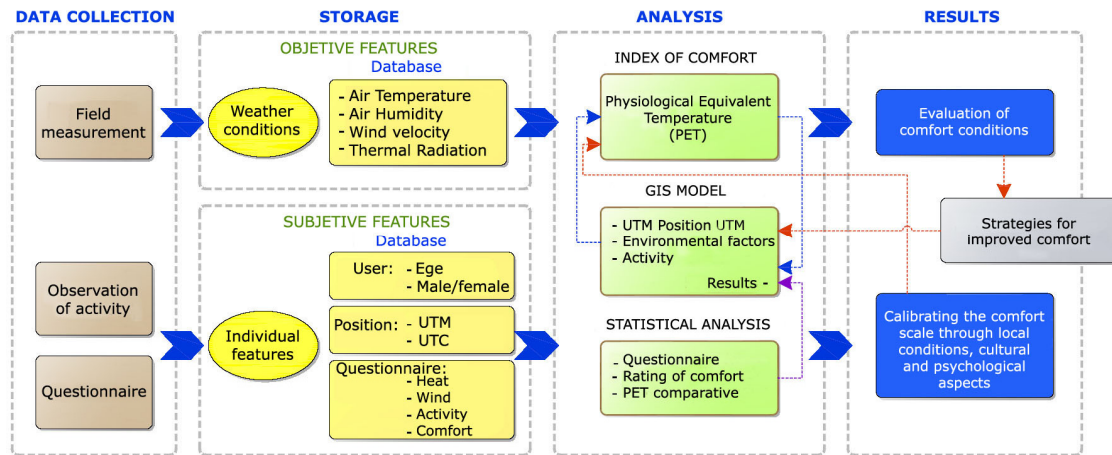


Figure 1

## Data Collection

The use of GIS provides anspacetime knowledge added to each piece of the information obtained. To do this, we use the temporal reference system of UTC (Universal Time Coordinated) and geographical system of UTM (Universal Transverse Mercator). The parameters of measurement are determined by the applied model of comfort and analysis of the sensations perceived by the people involved in the study. The PET index is based solely on four environmental indices (air temperature, relative humidity, wind speed and mean radiant temperature); the comfort rating scale does not require exact precision of calculation and the final result, which is a temperature stated in Celsius degree, is globally interpretable as a comfortable, warm or cold environment.

While performing the data collection (Figure 2), on the one hand we have objective data, which include atmospheric indices needed for the study and observation of the activity and utility of public spaces by people, and on the other hand subjective data, that include opinion surveys where individuals evaluate different aspects of sensations of comfort that they experience in those places.

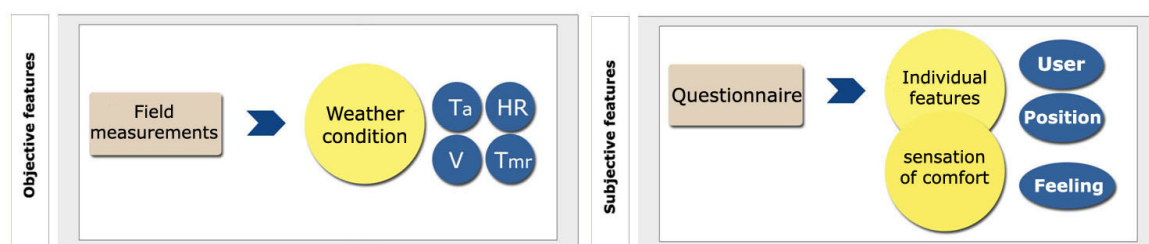


Figure 2

**Environmental Data :** The following data will be associated with the space-time position of the measurement and shall be transmitted to the storage and management unit of the comfort model. The collection of information will be done about four parameters:

- Air temperature ( $T_a$ ) : Measured according to ISO 7726 at the level of a pedestrian ( 1.1 meter above the ground).
- Relative Humidity (RH) : Measured in the same conditions as  $T_a$  .
- Wind speed ( $v$ ) requires some adjustment in value depending on the height at which one has made that data collection. Typically the air velocity is not measured in pedestrian level because in such a level it would be significantly influenced by the environment. The measurements are usually done at a higher level in order for the values to be more uniform.
- Mean radiant temperature (MRT) : Represents the heat in the form of radiation which has been emitted by the elements of the environment. It is the main element analysis [5], [6] and is obtained from the sky view factor . The use of high resolution 3D vectorial tools associated with GIS allows us to work in urban environments with buildings' influence on the sky view factor, which helps us to achieve a better understanding of the conditions. A practical tool and open source program is RAYMAN 1.2.

**Subjective Data, of utility and surveys:** The real sensation of comfort has to be evaluated by the individuals who are in that particular place at that specific time. There are different models of surveys based on ISO 7730 (Fanger method) on the overall thermal sensation of comfort and discomfort. From them, we propose a survey by rating from 1 to 5 points. New technologies allow us to simplify the questionnaire, make it more intuitive, and associate it directly to a user, whose data (age and gender) will be associated with any interaction with the application. Data on the clothing were put away, because they don't have a high influence on the assessment of comfort by PET. The survey (Figure 3) visually focuses on four issues: the warmth sensation, the wind sensation, the level of activity undertaken and the overall assessment of the degree of comfort.



Figure 3

### Data storage

This phase is about proceed from a real event, such as air temperature, to a virtual event which is associated with a value, and finally to some space-time coordinates and ranking in a database table. We distinguish two actions:

**Data characterization:** Consists of receiving real-time data of an event from environmental monitoring devices or through the informatic applications of the participants . Each of these events will be represented by its spatial, temporal, and the characteristic value like a corresponding event to a particular parameter of the research. This is how what we call a fact table (T) of corresponding event (x) will be completed [7]. This characterization of the obtained data is essential to work with GIS tools later, transferring the stored information in each fact table (T) to 3D maps for further analysis. An example of this is shown in the picture below (Figure 4) on temperature values taken at an interval of 10 minutes for making the fact table Tta .

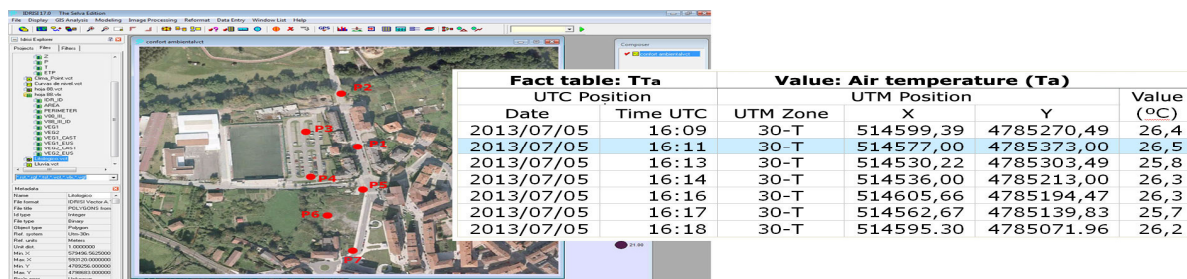


Figure 4

**Organization and creation of data bank:** The volume of received information makes it necessary to organize and store it for later use. There are different examples to establish storage systems of environmental data that integrate assessment process of OLAP (On-Line Analytical Processing) and GIS analysis. Via Internet, these processes allow us to analyze the recorded data and speed up obtaining results about the comfort model. The use of GIS technology makes it possible to expand information, but will always be roughly approximated data from which we can obtain complete information throughout the study area. Different statistical methods [7] exist in order to obtain superficial or three-dimensional results from the known data points.

Two levels of data organization are established:

**Daily database:** simpler level data. For a time period of one day divided into constant time intervals (5 minutes, 15 minutes, etc..). The time range of each interval can be set by the amount of information available on the site. The same time each event timetables are defined by the date and time of UTC and should be included in the corresponding interval. Whenever they happen to have their matching data (which means the same UTM position and UTC time in the same time interval) they may be stored by their mean value only if the matches are



considered punctual, or the time interval can be reduced in a way that they remain independent data events.

Database for other time periods: It will work with average values obtained from the first daily database and matching them up according to the time interval required. By working with these two organization levels, we achieve a higher accuracy for all the studied parameters. The process from data collection to storage, starts with receiving data at the information nodes, continues with organizing data in the fact tables, and finishes with joining data from different databases. Throughout all of this process, geolocation data (UTM) remain without modification. This does not happen to the temporal data due to their dependency on the required time intervals.

From the created databases, the next step is the calculation of PET index and GIS modeling of the obtained values in the study. The main problem to solve is how to work the existing information in the databases. Because of the weight of computer data and complexity of GIS programs, working on-line by using Web services do accelerate and simplify the process.

### **Transmission of results**

The presentation of results and their dissemination is a critical part of the study. The proposed methodology is designed from the collaboration of citizens providing information data through surveys and also observation of the utility of public spaces through GIS. This paper requires interaction of citizens in society and involves them as the main subjects of the gained knowledge from the research.

The presented methodology aims to achieve a better understanding of reality by increasing the amount of received information (environmental, activity and opinion) about the conditions of comfort. Furthermore, PET comfort index has been chosen among others for the simplicity of the results. In the same way that a home computer application transmits data to increase knowledge, the information of the obtained data can be made in order to improve their performance. Comfort related data of a public place can be very useful not only for the society but also for each of its individuals.

### **Conclusion**

The thermal sensation perceived by person is not based only in the thermo-physiological reactions produced by the thermal environment on the organism, but also in different psychological and behavioral aspects that are an important subjective variable in the process of perception. So we can see it in research works published in recent years, covering both objective aspects (environmental parameters) as the human component (including discreet observation of the activity in outdoor environments and questionnaire of feeling

Current technology allows for greater interaction between the individual and society. Citizen participation is and should be increasingly popular in all areas of development. This offers increased knowledge and information transfer. The use of new applications based on geographic information systems enables much more the interconnection. In the area of





thermal comfort will allow us a better understanding of reality and the opinion of citizens about the feelings of comfort or discomfort in a particular place. The discrete aspects of observation, questionnaires and even measuring devices embedded in mobile devices report higher and more accurate information for deeper understanding and improved comfort in outdoor environment.

The use of the Physiological Equivalent Temperature PET is ideal as an index of environmental comfort for its compatibility with GIS applications, by simplifying the required parameters and for ease of understanding and dissemination of results.

For research in this field we are working in the organization of new databases and compatibility between existing in the process of updating of the same. This also opens up possibilities in the investigation of environment predictor from the known variables.

The development of simple informatic applications for data collection and their transmission is the next task for the extension and knowledge transfer.

## Referencias

- [1] Chen, L. and Ng, E. (2012). Outdoor thermal comfort and outdoor activities: A review of research in the past decade. *Cities*, 29, (2): 118-125, doi:10.1016/j.cities.2011.08.006
- [2] Carlucci, S. and Pagliano, L. (2012). A review of indices for the long-term evaluation of the general thermal comfort conditions in buildings. *Energy Build*, 53, (0): 194-205, doi:10.1016/j.enbuild.2012.06.015
- [3] Kántor, N. and Unger, J. (2010). Benefits and opportunities of adopting GIS in thermal comfort studies in resting places: An urban park as an example. *Landscape Urban Plann.*, 98, (1): 36-46, doi:10.1016/j.landurbplan.2010.07.008
- [4] Moonen, P., Defraeye, T., Dorer, V., Blocken, B. and Carmeliet, J. (2012). Urban Physics: Effect of the micro-climate on comfort, health and energy demand. *Frontiers of Architectural Research*, 1, (3): 197-228, doi:10.1016/j.foar.2012.05.002
- [5] Lindberg, F., Holmer, B., Thorsson, S. and Rayner, D. (2013). Characteristics of the mean radiant temperature in high latitude cities-implications for sensitive climate planning applications. *Int.J.Biometeorol.*, 1-15, doi:10.1007/s00484-013-0638-y
- [6] Tan, C.L., Wong, N.H. and Jusuf, S.K. (2013). Outdoor mean radiant temperature estimation in the tropical urban environment. *Build. Environ.*, 64, (0): 118-129, doi:10.1016/j.buildenv.2013.03.012
- [7] C. Dang, C., M. Iwai, M., Y. Tobe, Y., K. Umeda, K. and K. Sezaki, K. (2013). A framework for pedestrian comfort navigation using multi-modal environmental sensors. *Pervasive and Mobile Computing*, 9, (3): 421-436, doi:10.1016/j.pmcj.2013.01.002



## **Bio-climatic Design Handbook: designing public space to reach urban sustainability.**

**Abstract:** *The "Bio-climatic Design Handbook: guidelines for the development of planning regulations" is a tool for urban planning and design professionals planning for the construction of public space taking into account bioclimatic and environmental standards. Based on environmental conditions assessment, urban design guidelines are given. These take into account various scales; from the territory to the microclimatic reality. From these general keys for the design of public space the handbook performs recommendations on specific case studies. The application of bioclimatic techniques in urban design promotes comfort in the public space and the respect for the existing environment, while it influences the energy consumption of buildings that conform this open space. The tool was developed in the context of BIOURB project, where Spain and Portugal cooperate writing this bilingual handbook. The case studies are located in this cross-border region.*

**Key words:** *public space, bio-climatic techniques, urban design, environment, urban microclimate, comfort.*

### **Introduction**

This Handbook is a tool for the design of public space through bioclimatic techniques and environmental criteria. It was developed as a part of the BIOURB project, a proposal aiming to work on the Bio-constructive Diversity in Spanish-Portuguese Border, Bioclimatic Construction and its adaptation to contemporary Architecture and Urbanism. The Handbook was developed within the project action "Urban Climate". Sustainable and bioclimatic design considers environmental parameters to intervene in the Urban Climate, in order to influence the microclimate conditions, and therefore hygrothermal comfort both in buildings and open spaces. The bioclimatic design of public space is a requirement to achieve sustainability in our cities, both in new urban development and urban retrofitting and regeneration.

Various scales of design are covered: from the environmental conditions of the territory to the microclimatic scale. The Handbook explains and develops specific methodologies for environmental studies providing guidelines, graphics and specific recommendations for the design of comfortable public spaces and environmentally friendly urban interventions.

### **Aims and objectives**

The main objective of this Handbook is to create a professional-oriented tool for planning and urban design based on bioclimatic and environmental criteria, aiming to create comfortable and sustainable urban environment and public space.

Climate regulation in public space is gradually becoming an important issue when approaching urban design. The Handbook is a tool for the development of future urban planning of the municipalities belonging to the selected climates, in order to incorporate improvements that increase the comfort of urban space and minimize energy demand of buildings, but specially focused on public space design as a key element to reach these



goals. It also aims to serve as a tool to guide rehabilitation, conditioning and improvement of existing urban spaces.

This Handbook is well aimed at everyone involved in the design of public space in cities at all scales, from government technicians to planning professionals and urban designers. It becomes a tool for professionals whose discipline influences can contribute to create a more livable and sustainable city.

### **Part 1: Territorial support**

In this section, we classified, developed and explained a number of tools to make an urban plans, regulations or projects. These tools were organized according to the following topics: hydrology, soil potential for agriculture and forest, possibility of soil urbanization, topography, land orientation, landscape units and vegetation.

The hydrology section discusses water cycle with special reference to two problems that climate change looming will set as top priority in the territory covered by the Handbook. The first relates to the water supply. How can we cover the future water needs with a lower rainfall and with a much more concentrated in space and time rainfall pattern. Guidelines for water balance analysis and groundwater aquifers protection are given, and water supply and sewage are analyzed. The second relates to the likely floods that such rainfall patterns will cause, so basic recommendations for flood risk areas detection are given.

In a context in which the recovery of local livestock and agriculture is gradually becoming a necessity, the analysis of agricultural and forest land soil is essential. Preserving this kind land and soils is essential if we are thinking in local productive activities. After preservation of this lands, it is necessary to activate the production. The tool outlines the guidelines to determinate the agricultural and forest soil suitability, taking into account different factors, explaining them and providing tables to establish the classes of agrological suitability of land uses.

However, although it is a commonplace that the land allocated to urban development should be the residual one, not all residual soil is suitable to be urbanized according to the ecological and economic cost that this could entail. Guidelines for soil mapping and suitability determining for being urbanized are given, analyzing excavation ease, the absence of aggressive chemicals, the bearing capacity of the soil, the possibility of differential settlement and soil contamination .

Topography and orientation of land is a priority for the organization of territories and the design of cities that consume less energy, taking advantage of environmental conditions and achieving comfort for citizens. The Handbook makes recommendations about appropriate slopes for each uses of cities, prioritizing accessibility. Furthermore, the relationship between orientation and slope is described providing guidelines for the analysis and identification of outstanding sunny and shady areas.

Landscape is not only important as cultural heritage or tourist resource, but as a key for understanding the ecological functioning of the environment in which the city is located, besides being its most important value is to create identity. Therefore, a synthetic landscape analysis methodology is proposed aiming to bring together these factors to constitute an assessment tool.

Vegetation provides valuable services to urban areas. It is almost the only physical element that the designer can use to modify urban microclimate, creating shade where needed, letting the sun pass, performing functions as a barrier against wind or modifying evapotranspiration. A study of different properties of local vegetation and green areas and their understanding is proposed: major ecosystems, ecological corridors and their size or the capacity of local vegetation to climate control.

## **Part 2 : Location and climate**

As an approach to the relationship between city and climate, this Handbook outlines theoretical basis by explaining three concepts: The climatic scales, the physical basis of climate research and the physiological basis of comfort.

When it comes to the mechanisms of heat exchange between users and their environment, solar radiation is the dominant variable in open spaces. Urban development strategies focus on the definition of the environmental conditions conducive to sun exposure or shading of outdoor spaces, depending on the needs identified through the climate study. Thus, strategies for sun protection and exposure are explained while the influence of orientation and slope are defined as essential parameters.

Despite the difficulty of analyzing air flow in the urban environment, wind is a determining factor for comfort in open spaces, both its mechanical and thermal effects. Variations in air flow produced by the built environment is discussed, wind obstructions produced by topographical obstacles, the influence of surface finish and texture, the microbreeze creation and the possibilities of pollution dissemination. Urban design recommendations are offered in each of the different sections, firstly distinguishing between the needs of wind protection or ventilation, secondly recommending actions to increase microbreezes and to diminish the negative effects of air pollution.

Water in its different phases and through different phenomena plays an essential role for defining the urban microclimate and for achieving the hygrothermal comfort in cities. Thus, the possible strategies of drying and wetting the environment are analyzed. Water cycle in the city is a key element to achieve an environmentally sustainable city, by reducing runoff water and increasing soil permeability. This Handbook goes beyond the bioclimatic parameters to achieve an environmental approach. This fact has led to the inclusion of specific recommendations for water management, considering alternative solutions.

Vegetation has an important effect on the urban microclimate at all scales and plays an important role in the urban energy balance. It is analyzed focusing on its interaction with aforementioned variables: air temperature, humidity, radiation, air velocity and air and noise pollution. Specific recommendations are explained and different scales are considered, from the opportunities provided by the distribution of vegetation at urban scale to the effects of a single tree, including the effects of small plant masses.

Finally, the finishing materials of the city influence both thermal and hydric balance in cities, producing a direct impact on the heat island effect and the sustainability of water management, as well as the hygrothermal comfort. Therefore, these materials are the elements that are in permanent contact with citizens. Parameters such as albedo, emissivity and absorption, permeability (Fig.1.3.), texture and thermal inertia are analyzed, studying its influence on the hygrothermal conditions and producing design recommendations.

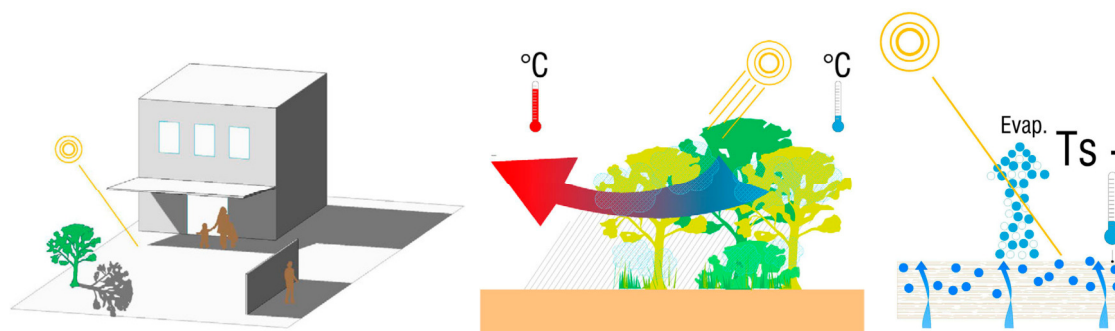


Fig.1. Recommendations: 1.1. Solar protection, 1.2. Micro-breeze creation, 1.3. Permeability of materials.

### Part 3: Case study: Portugal - Spain border region

This Handbook is completed through a study developed in the Portugal-Spain cross-border region, suggesting specific recommendations on urban bioclimatic design on this area. The analysis of the recommendations has been carried out in a series of steps, starting territorial and climatic descriptions, proposing then specific design recommendations for the selected cities and finally applying these recommendations to two public spaces. General recommendations were developed for the region and specific ones for each location.

The analysis and interpretation of topography and hydrology allow us appreciate the importance of orientation, slopes or nearby water sources in sustainable urban design and planning. Adding water balance analysis allows to know when and where interactions are critical and how to use them to mitigate the adverse effects of climate.

Köppen-Geiger climate classification has been used to choose case study cities. Five cities have been selected León, Zamora and Salamanca in Spain and Mirandela and Bragança in Portugal, representing the three main climates detected in the area. Climate data was analyzed in relation with the spatial location of cities. In the absence of measurements in the inner cities with sufficient spatial and temporal coverage, data provided by weather stations located around the city has been used for climate analysis and the establishment of general recommendations for planning. The climate description has been developed through



analyzing basic climatic variables (temperature, precipitation, relative humidity, etc.), radiation and wind (wind roses separating months according to the need of ventilation or wind protection). Bioclimatic Olgay diagrams are performed and compared to identify conditioning requirements necessary to reach comfort in free spaces. (Fig.2)

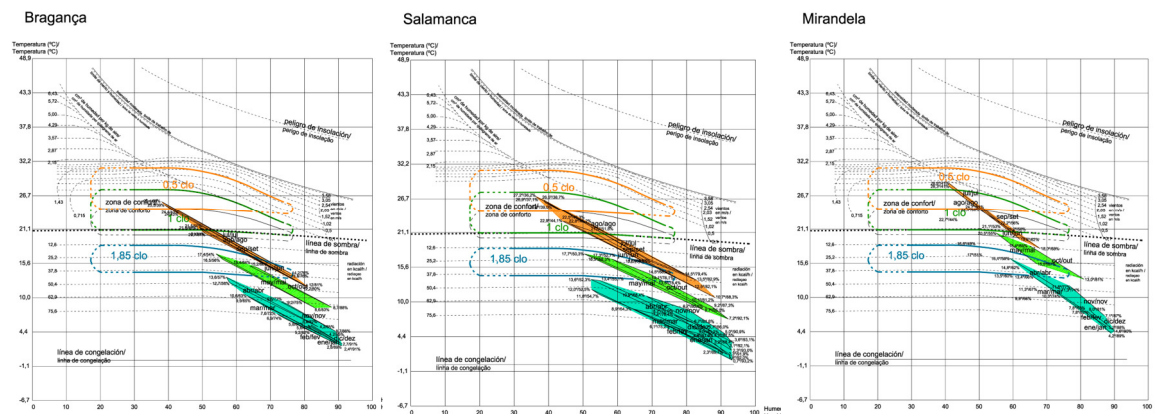


Fig.2. Olgay diagrams of Bragança, Mirandela and Salamanca.

The information represented on these diagrams leads to identify a seasonal pattern unlike the conventional one. Sun exposure is necessary to reach comfort during most of the year, while shaded areas are only needed in the central hours of the hottest summer months (July and August). Deciduous trees are therefore needed to allow solar radiation to reach public space. Spaces which are sheltered from the wind in autumn, winter and spring will allow comfort during most of the year. When it comes to materials, high thermal inertia and emissivity will be necessary for paving and other surfaces. However, street furniture (benches, children's games, etc. . ) should present low thermal inertia.

Once the design strategies are defined, specific design recommendations are established. Given the similarity of the needs on climate conditioning in the analyzed cites, global recommendations for the area have been made, later describing the specific needs of the regions when necessary. Based on the climatic recommendations developed in the first and second part of this Handbook, suggestions applied to the region have been made for three different periods: winter, spring and summer-autumn. Specific sunlight studies for different types and sizes of spaces in the urban fabric have been developed, simulating examples of square spaces and streets north-south and east-west oriented. Each city's wind roses have been interpreted exemplifying main wind directions and strategies to place wind barrier for wetting or protection. Selected strategies were linked to wetting, vegetation and the various materials used in the design of public space.

Finally, an example of a public square is developed to propose solutions to get to the synthesis and discussion of the strategies proposed in the Handbook (Fig.3). This case study exemplifies the way to combine the different strategies that so far have been brought separately. Thus the relationship between the various parameters of sunlight, wind, water,

vegetation and materials applied in the urban morphology and design of open spaces can be observed.

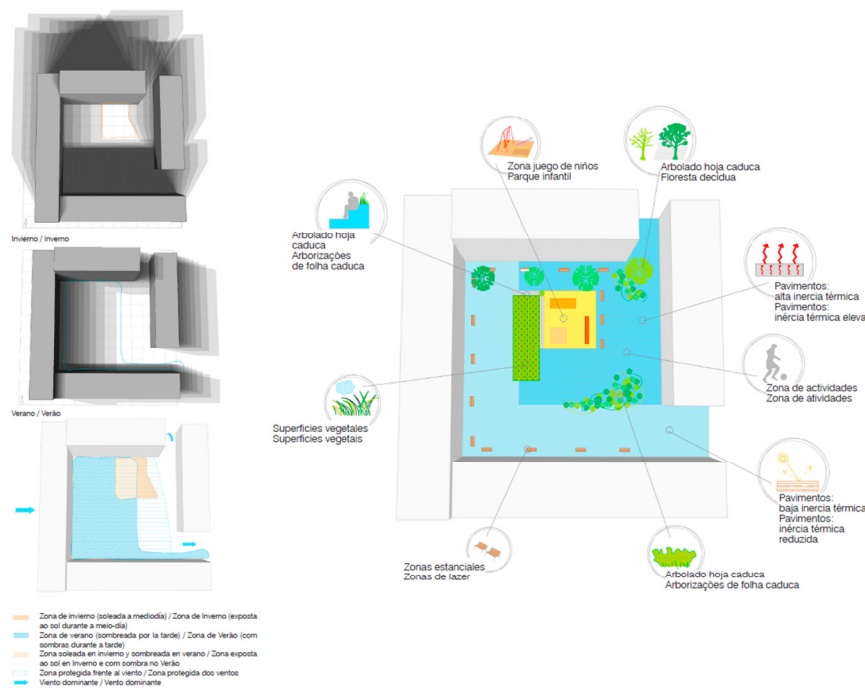


Fig.3. Public space analysis and proposal.

The final chapter of this Handbook reflects the intense work of documentation including a detailed bibliography with key words and abstracts of the main references, aiming to help professionals involved in urban planning and design to deepen their knowledge in the field.

## Conclusions

This Handbook presents a comprehensive content organized in various scales as well as in different application degrees. Environmental conditions are the basis for explaining the relationship between urban environment and climate through the various scales of design, from the environmental conditions of the territory to the microclimatic weather reality. In addition to include this variety of scales, this tool provides guidelines and recommendations that go from the general to the specific, including general guidelines and recommended readings, application to the Portugal-Spain cross-border region and case study examples of public spaces.

This Handbook introduces many bioclimatic urban design environment collecting the latest advances in the field of urban climate and microclimate, as well as including literature from environmental planning recognized experts. The description of the information and recommendations is based on various theoretical sources and supported by multiple charts and graphs to help design comfortable public spaces for people while respecting the existing environment. It is therefore a tool that brings scientific knowledge to professionals in this area by proposing practical application in a direct and didactic manner.



The dissemination of the Handbook is key to help achieve more comfortable and sustainable cities. This tool is an Internet open access resource. It is available on the website of BIOURB project and the Open Access webpage of the Polytechnic University of Madrid. It has reached 2,000 downloads just in this last website. Communication events about the results of the BIOURB project have been held in which this Handbook and its contents have been presented, both in the geographical region of analysis and the Polytechnic University of Madrid. Also, this Handbook has been sent to city councils that took part in the BIOURB project, to become a useful tool for experts and urban planners of the study region.

It is ultimately a tool for more livable and sustainable, more comfortable and efficient cities, through the environmental design of public space.

### Acknowledgments

This Handbook was developed within the BIOURB project, Cross Border Cooperation Programme Spain - Portugal, with the support of the EU and the co-financing of European Regional Development Fund (ERDF) and Cross-Border Co-operation Programme Portugal-Spain (POCTEP).

### Bibliography

- Baumüller, J.; Hoffmann, U.; Reuter U. (2008). *Climate Booklet for Urban Development*. [online]. Stuttgart. Ministry of Economy Baden-Wuerttemberg.
- Eliasson, I. (2000). The use of climate knowledge in urban planning. [online]. *Landscape and Urban Planning*. Nº 48 (2000) [2012-04-25], p. 31- 44.
- Erell, E.; Pearlmuter, D.; Williamson, T. (2009). *Urban microclimate: designing the spaces between buildings*. London. Earthscan.
- Fariña Tojo, J. (2009). *La ciudad y el medio natural*. Madrid. Akal.
- Hernández, A. (Coord.). (2013). *Manual de diseño bioclimático urbano. Recomendaciones para la elaboración de normativas urbanísticas/ Manual de Desenho Bioclimático Urbano Manual de orientações para a elaboração de normas urbanísticas*. Redacción: Fariña, J.; Fernández, V.; Gálvez, M.A.; Hernández, A.; Urrutia, N. Bragança. Instituto Politécnico de Bragança.
- Higueras García, E. (2006). *Urbanismo bioclimático*. Barcelona. GG.
- Landsberg, H. (1981). *The urban climate*. New York. Academic Press.
- Luxán García de Diego, M. et Al. (2011). Diseño Bioclimático en Canarias. en AA.VV.: *Sostenibilidad energética de la edificación en Canarias. Manual de diseño*. Instituto tecnológico de Canarias. Neila González, F. J. (1999). Diseño de ambientes exteriores. *Cuadernos del Instituto Juan de Herrera*. Madrid. Instituto Juan de Herrera. Nº 45.
- Nikolopoulou, M. Coord. (2004). *Designing open spaces in the urban environment: A bioclimatic approach*. [online]. CRES (Centre of Renewable Energy Resources). Greece.
- Olgyay, V. (1963). *Design with climate*. New Jersey: Princeton University Press, Princeton.
- Reed. *Arquitectura y clima. Manual de diseño bioclimático para arquitectos y urbanistas*. Barcelona. GG.

## **Emergent Trends in Architecture and Urbanism in Modern Cairo: Shifts in the Built Environment**

**Abstract:** *This paper examines the shifts and transformations of the different built environments within Greater Cairo's urban agglomeration and argues that shifts and transformations are inevitable in order to achieve sustainability, especially urban social sustainability in the urban context.*

*It starts out by depicting a quick image of modern Cairo, starting 1798, while highlighting the shifts and transformations that inevitably occurred in the built environment over time. New Cairo City- to the east of Greater Cairo- is taken as an example of these contemporary shifts and transformations, demonstrating the problem of unsustainable urban development and concentrating on the lack of urban social sustainability. At the end, an approach towards a solution to achieve urban social sustainability within the urban context is discussed.*

**Keywords:** *Cairo, shifts, transformations, built environment, New Cairo City, Urban Social Sustainability*

### **Shifts and Transformations of Modern Cairo**

Cairo is a dynamic city that has been shaped by distinct urban-fabric-accumulations over time. In 1798, the French invaded Egypt for three years, during which the Egyptians were confronted with the full impact of Western civilization. Then came the Rule of Muhammad Ali from 1805 till 1848, when the foundations of modern Egypt were truly laid. Khedive Ismail took over the rule of Egypt, between 1863 and 1879 and built Wasat Al-Balad: a new Europeanized quarter- based on Haussmann's planning methods, with a well-defined street system- to the west of the old, traditional city. In 1882, under the British Occupation, a unique colonial city had been developing; and in 1905, with the mechanization in public transport, Heliopolis- a suburban residential quarter- was built to the northeast of the city *designed in the latest manner of Ebenezer Howard's Garden Cities*- ten kilometers from the centre of Cairo. It is worth mentioning that not only has the transportation link allowed the growth of Heliopolis itself, but it has also resulted in the emergence of a continuous band of urban settlements stretching all the way between Wasat Al-Balad and Heliopolis. Between 1882 and 1937, Cairo's population increased greatly and by 1950, the city's economy had enjoyed a boom and it was ready to expand at a scale never before seen in history- (Abu-Lughod, 1971). By then, large migrations from the countryside had started taking place and until the early 1960s the city expanded substantially through state-aided social/ public housing projects, especially after the 1952 revolution- (Sims, 2012).

By 1960, under Nasser's Regime, Cairo's rapid population growth resulted largely from natural increase, as well as from large migrations from the countryside, which not only resulted in the formation of planned districts, such as Mohandessin over agricultural land on the west bank of the Nile, but also in the emergence of the first informal settlements. The June 1967 war stopped all of Cairo's *planned* urban expansions and Egypt rapidly shifted to a



wartime economy; this continued until the October 1973 war. However, at that time, informal settlements had continued to grow- (Sims, 2012).



Figure 1- from left to right: Cairo in the early 19<sup>th</sup> century; Cairo in the second half of the 19<sup>th</sup> century, showing the development of Wasat Al-Balad; the development of Heliopolis in the early 20<sup>th</sup> century; the built-up area in 1950 in comparison to the built-up area in 2009; large informal settlements of Greater Cairo in 2008  
Sources: Scharabi, 1989; Elmokadem, 1997; Heliopolis Company Book, 1969; Sims, 2012

Nasser's policies were followed in the mid-1970s by President Sadat's *infitah*, or Open Door Policy, which had deep effects on the urban development of Cairo. Madinat Nasr (Nasr City), a huge, 7000-hectare concession on state desert land, directly to the south of Heliopolis, became the most significant city extension. Also, by that time, plans to execute new urban communities to the east and to the west of Cairo had been unavoidable due to the numerous problems the city was facing because of the rapid increase in population.

From 1986 to 1996, Greater Cairo, as a whole, witnessed a significant slowing of its population increase; however, informal settlements were still growing substantially, because of the inability of the government to meet the housing demand. In terms of population shifts in the existing city, the most significant phenomenon was the depopulation of the older, especially historic districts in central Cairo- (Sims, 2012). In the 1990s and 2000s, new urban communities have seriously taken off, representing an important shift and transformation in the development of the urban agglomeration of Cairo. At that time, there have been a number of improvements, especially in terms of infrastructure: the ring road was built in stages, the 26<sup>th</sup> of July corridor to the west, and more flyovers have been constructed- (Sims, 2012). In 2006, Greater Cairo's population had reached almost 16 million inhabitants and in 2012, it had reached almost 18 million, most of which from massive population increases in informal settlements.

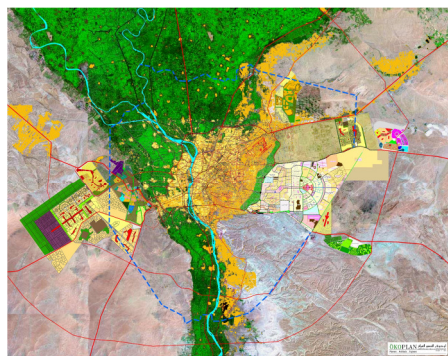
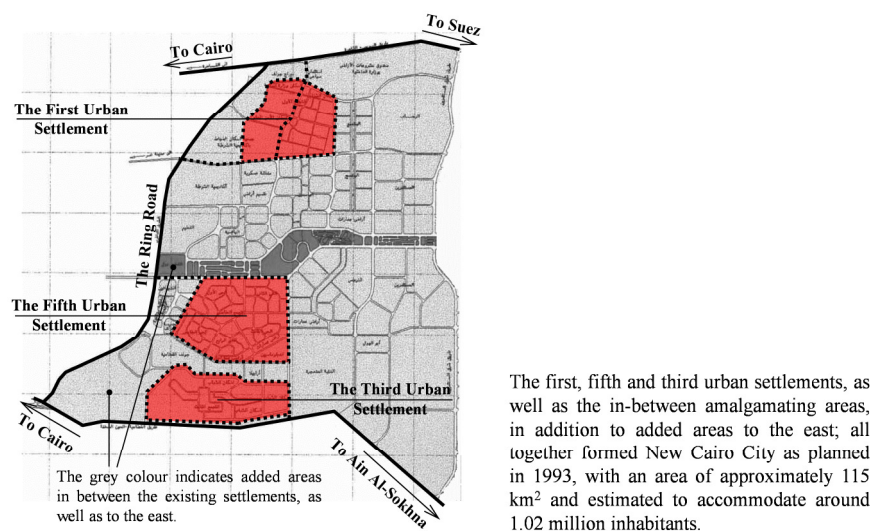


Figure 2- Greater Cairo Region in 2009, including the new urban communities to the east and to the west of the ring road- Source: Ökoplan Engineering Consultations, Cairo



### **New Cairo City: A Representation of the Contemporary Shifts and Transformations in the Built Environment of Greater Cairo**

In 1993, ten years after the 1983-General Planning of Greater Cairo Region was prepared and due to the numerous problems that resulted from the rapid increase in population and internal migration, lots of investments and construction activities have been directed to the new urban settlements located to the east and west of Cairo. The result was an increase in the areas designated for new urban settlements and a reconsideration of their distribution around Greater Cairo; in particular for the first, third and fifth urban settlements, lying to the east of the Ring Road, and included between the Cairo-Suez Road to the north and the Cairo-Ain Al-Sokhna Road to the south. These three small urban settlements have, since then, been contained within the borders of one large urban settlement called: New Cairo City; and the in-between areas have been divided and sold to individuals, as well as to investment companies that established large residential and recreational projects on them. In addition, new areas have been added to the east of the three urban settlements, designated for residential use- (El Khorazaty, 2006).



*Figure 3- The emergence of New Cairo City- Source: El Khorazaty, 2006*

The combination of the first, third and fifth urban settlements, as well as the filled-up, in-between areas and the added parts to the east had formed New Cairo City, which then covered an area of approximately 115 km<sup>2</sup> (11,500 hectares) and was planned to accommodate 1.02 million inhabitants- (El Khorazaty, 2006). In 1998, an extension had been planned to the east of the previously laid out urban settlement, increasing the area of New Cairo City to reach 188.16 km<sup>2</sup> (18,800 hectares), to accommodate, in total, approximately 4 million inhabitants. From the beginning, New Cairo City has been meant to become a center of regional services, including office parks, as well as recreational, commercial and educational activities.

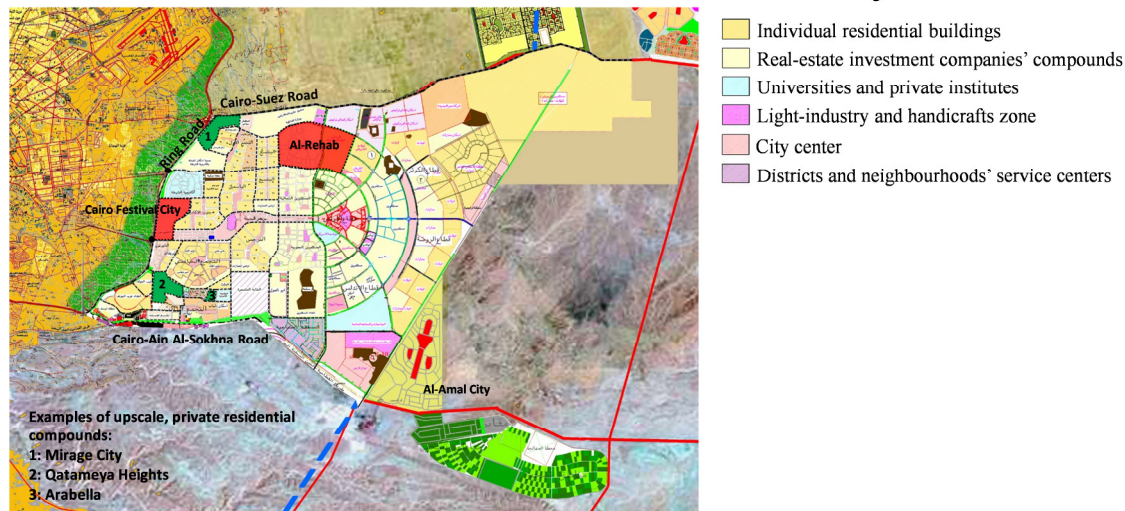


Figure 4- New Cairo City master plan, showing the residential areas, the neighbourhoods and the hierarchy of service centers- Source: Ökoplan Engineering Consultations

Referring to Figure 4, and through field observations, it is noticed that urban development areas in New Cairo City include, Private Gated Residential Compounds, *fenced with strong security controls*; Semi-Private Gated Residential Compounds, *fenced, but open to the public with minimal security controls*; Public Housing, *provided by the government*; Private Individual Residential Buildings, *outside residential compounds*; Services and Amenities; Individual Office Buildings; and Large Mixed-Use Developments, *including office parks, as well as retail and entertainment complexes, owned by private investors on fairly large parcels*. It is thus clear that New Cairo City represents a shift in the urban development of Greater Cairo as a whole, which is clear in the emergence of new land uses and activities: ones that weren't there in the existing city, within the first ring road.

Also, the way the city is being developed is different from what occurred over more than 1000 years in the existing city within the ring road. It is worth mentioning that New Cairo City is still in the development process and has not yet reached its planned population targets. Despite this, the growth of New Cairo City over the past 20 years has not been incremental. On the contrary, the government has always been providing the main road and infrastructure networks and has been selling parcels to investment companies, as well as individuals to develop their own projects, according to the building regulations and codes of New Cairo City. As a result, the whole urban settlement has spread out and has long been defined over an expanse of desert land that is approximately 15 km wide, to the east of the ring road and 12 km long, from the Cairo-Suez Road to Al-Ain Al-Sokhna Road: a land area, not far from that of the existing city, within the first ring road. This has taken place, at least over the past ten years, with many parcels left empty, until the real-estate market dynamics allow their development.

Another observation is that the *physical* plan of the city is not flexible enough to accommodate changing demands and sustainability measures. In order to achieve sustainable urban development, the three pillars of sustainability have to be accommodated in the



planning and design of the city. Through field observations, it is clear that the city is somewhat economically sustainable, with all the services it provides- *including offices, large commercial/ retail complexes, schools, universities and others*- and accordingly the job opportunities it creates. Moreover, within New Cairo City, there is a light-industry/ handicraft zone, providing an economic base. In addition, it is adjacent to the industrial area of Al-Amal City to the southeast. Moreover, environmental sustainability is not achieved either on the urban scale or on the building scale, especially that it is not a building requirement in the development of any project- it is an issue left for the developer to decide. Likewise, the physical environment does not offer social sustainability. This is clear from the following observations:

- The low population densities within the city.
- The lack of communal public spaces that don't involve retail or any other "paid" services. This, *in turn*, causes deficiencies in social interactions and in the creation of social networks in the community.
- The lack of public transport connections within the city; it is worth mentioning that public transport connections to the "Existing City" are also non-existent.
- The existence of low safety measures for pedestrians in wide streets, designed for high-volume traffic with minimal pedestrian facilities. The city is not exactly walkable because of poorly designed and poorly constructed streets: there is a shortage of sidewalks and pedestrians face difficulties in crossing streets. The problem might be simpler inside the neighbourhoods, where streets are smaller and the scale is more intimate.
- The existence of gated residential compounds: a phenomenon that deliberately separates a sector of the people living in the city from the others, causing an incision in the society. Nevertheless, in case of gated compounds, safety and social interactions *do* exist. In addition, people living there have a better sense of place: they *know* and *feel* that the place *belongs* to them: a fact that makes social sustainability more effective.

Finally, it is worth pointing out that because of the lack of urban social sustainability, the people living in New Cairo City will transform their surrounding built environment by themselves, not according to a general framework or a collective vision, which will result in developing the city randomly instead of incrementally building up an organized complexity that is responsive to transformations over time.

### **Conclusion: An Approach towards a Solution to achieve Urban Social Sustainability within the Urban Context**

Through the previous analysis, it has become clear that shifts and transformations in the built environment are inevitable in order to achieve sustainability, especially urban social sustainability. It has also been observed that informal settlements have emerged in response to socio-economic factors that occurred in the city of Cairo over the years and that their existence- *however negatively perceived*- has actually sustained the metropolis and has



allowed the large numbers of inhabitants to find the shelter, which the government has not been able to provide for years.

Nevertheless, *because of the numerous problems found in informal settlements, and the rapid urbanization in Cairo*, the government has shifted the built environment towards new urban communities, for which clear physical master plans have been developed and have *mostly* been implemented, however, lacking many aspects of sustainability. In order to reach sustainable urban development, the three pillars: economic, environmental and social should be accommodated in cities. The government *and* the people should work cooperatively to include environmental and economic aspects in building laws, regulations and codes. The first two pillars (environmental and economic) are not the focus of this paper, but the concentration here is on the social aspects, which- *if not tended to*- inevitably cause unwanted transformations.

After briefly examining New Cairo City, it has become clear that urban social sustainability has almost *not* been achieved for the city as a whole. In a recent report, created in collaboration between The Berkeley Group, Social Life, and Prof. Tim Dixon from the University of Reading, entitled *Creating Strong Communities: How to Measure the Social Sustainability of New Housing Developments*, it is stated that:

*“Social Sustainability is about people’s quality of life, now and in the future. It describes the extent to which a neighbourhood supports individual and collective well-being. Social sustainability combines design of the physical environment with a focus on how the people, who live in and use the space relate to each other and function as a community. It is enhanced by development, which provides the right infrastructure to support a strong social and cultural life, opportunities for people to get involved, and scope for the place and the community to evolve.”* - (Bacon, Cochrane, & Woodcraft, 2012)

From the above statement, it is clear that in order to achieve urban social sustainability in an urban context- *in this case, New Cairo City is taken as an example*- urban planning should address and enhance the following aspects:

- Public participation in decision-making should be adopted when planning areas in the city. This allows the people to develop a sense of belonging to a place: they know it is theirs and they act accordingly.
- Through public participation methods and through observing the places where normally there are large volumes of pedestrians, it can be decided where to develop communal public spaces, including- *but not limited to*- parks, in order to start establishing social networks in the community.
- Population densities should be increased according to a collective vision and based on agreed upon guidelines.
- Public transport networks within the city must be established so as to achieve better connectivity.





- Suitable sidewalks and safe crossing points must be established to give pedestrians the required safety, security and ease to walk through the city.
- It is also suggested to design bicycle lanes, adjacent to car lanes to provide another environmental-friendly mode of transportation.
- Gated residential compounds should be minimized.

It is also suggested that cooperative organizations carry out the projects within the city, since a “co-operative” is a form of organization that is owned and democratically controlled by its shareholders and members. A co-operative is also known as a mutual organization or a “co-op”, run for the mutual benefit and support of its members or the promotion of a specific purpose or a social benefit.

Transformations over the years are unavoidable, but when they happen according to a certain collective vision, the result is organized complexity. It is thus important to allow the people to participate- *with the regulating body*- in a collective vision for the place where they are to live. This gives the community a kind of stability, pride and a sense of place, which- *in turn*- guarantees a good quality of life and urban social sustainability.

## References

Abu Lughod, Janet (1971). *Cairo: 1001 Years of the City Victorious*. (Princeton, New Jersey, USA: Princeton University Press).

Elmokadem, Ashraf (1997). *Die Kolonialarchitektur des historischen Wohn- und Geschäftsviertels “Wasat Al-Balad”, Kairo*. (München: CS Press).

Scharabi, Mohamed (1989). *Kairo: Stadt und Architektur im Zeitalter des europäischen Kolonialismus*. (Tübingen: Verlag Ernst Wasmuth).

Sims, David (2012). *Understanding Cairo: The Logic of a City Out of Control*. (Cairo, Egypt: the American University in Cairo Press).

El Khorazaty, Tamer (2006). *Urban Design Guidelines: A Solution for Rectifying the Visual Disorder of New Cairo City*. A paper published in the scientific journal of Hochschule Nuertingen, Germany.

Bacon, N., Cochrane, D. and Woodcraft, S. (2012). *Creating Strong Communities*, the Berkeley Group, London.

Heliopolis Company Book, Egyptian Surveying Authority (ed.) (1969). *The Suburb of Heliopolis: its present and its future (in Arabic)*. (Cairo: Heliopolis Company for Housing and Development and the Egyptian Surveying Authority).



## **An approach to urban micro space sustainability. Sustainable assessment instrument**

Gómez Nersa<sup>1</sup>; Higuera Ester<sup>2</sup>; Ferrer Mercedes<sup>3</sup>

<sup>1</sup>Instituto de Investigaciones, Facultad de Arquitectura Universidad del Zulia - LUZ, Maracaibo Venezuela

<sup>2</sup>Departamento de Urbanística, Escuela de Arquitectura Universidad Politécnica de Madrid – UPM, Madrid España

<sup>3</sup>Instituto de Investigaciones, Facultad de Arquitectura Universidad del Zulia - LUZ, Maracaibo Venezuela

**Abstract.** *The bet on new urban growth demands sustainable assessment instruments to keep coherence among the components that intervene in the urban ecosystem and environment, which supports them. This focus of this work is centered in the micro urban scale and the main purpose is to move forward an instrument – guide – of plan assessment from the bioclimatic perspective and to propose sustainability strategies to be used in decision making in order to evaluate and design the micro space among buildings. This work proposes: (1) literature review about assessment systems, analysis scenarios and experiences achieved at an international level about key components of micro climatic scenarios of construction; (2) urban and environmental variables and indicators selection according to local “micro urban reality”, urban morphology and micro climate; and (3) a systemic proposal and key elements that act as control guides and sustainable design of urban micro space.*

**Key, words,** *urban sustainability, urban micro space, assessment guide, variables, parameters-indicators of sustainability.*

### **Introduction**

One of the actual great challenges is the promotion of more sustainable urban models with a more efficient use of resources (Rueda S, 2004). This manifests the need to act at different scales of public space by implementing new and innovative strategies that promote the use and appropriation of space and encourage sustainable changes in the urban field as well as to assume the objective of maintaining coherence among the components that intervene in the urban ecosystem along with the environment that supports them (Nikolopoulo et. al, 2003). Therefore, the approach of the work points toward the establishment of an instrument – guide – that states micro climatic scenarios as a tool of assessment and sustainable design supported by the microclimatic, morphotypological characteristics and its interconnection in the scale of urban micro space.



The particular interest of the work is to pose how to improve relationships and conditions of micro space from a systemic integral vision that combine the urban and environmental variable in supporting the social element in a balanced way. This position identifies with current urban purposes (sustainable development, social cohesion, quality of life) that pose the incorporation of new strategies to join in planning techniques to move towards a sustainable relationship (European Union, 1996). The definition of a systemic and comprehensive strategy for adequacy and control of intervening variables may act as a tool-guide of control and design in the urban micro scale.

So, considering this purpose a *literature review* on sustainable measures, assessment systems, variables and key components in the construction of micro climatic scenarios is stated in the first place. Secondly, dimensions of urban field, *environmental and urban variables and indicators consistent with local "micro urban reality"*. Third, a proposal of scenarios and different "situations" modeling as well as interrelationship of determinant key variables, analysis control guide and micro space designing.

## **1. Literature Review**

Current outlook shows a great quantity of approximations and the concurrence of many sustainable parameters that have been shown as a standard tool since its incorporation in Local Agendas 21. Besides the recognition of their importance, agreed strategies related to sustainability that allow knowing the main problems considered and used strategies are stated in published literature that directly discusses the role in sustainable development.

Investigations have centered their efforts in measurements and sustainable assessment systems in order to guide urban, environmental and social issues. Studies mostly focus on objectives, analysis scenarios, data availability, acting scales, selection, assessment and variables and indicators structure to promote urban sustainability. Likewise, they offer information on urban field dimension specifically about physical and environmental dimension linked to the social element. On the other hand, these studies highlight that physical structure confers an order that gives a series of time-spatial benchmarks that supports the desired social model, and manifest in the organization and distribution of elements in order to provide the scenario for ordinary activities.

It is considered that the mixture and interaction of typologies can remarkably improve social-spatial cohesion and act as a mechanism to establish corrections in order to allow the identification with the constructed environment. For this reason, space must be thought as a unit where climatic and physical components organize in a comprehensive vision that conditions the built environment and confers living character and social relationship. Studies address men-means-environment relationship that deals with the materialization of urban form and intervening elements within the adequate treatment and design to place. Building heights, density, compactness, insulation, vegetation, sun exposure, wind exposure, shadows, distances, sizes, superficial materials and pavements are stated as intervening elements

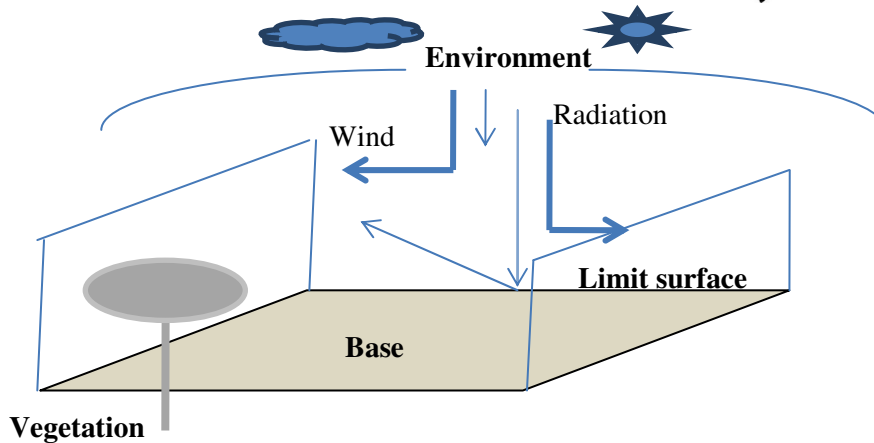
(Olgyay, 1968). All of these are recognized as intervening factors in thermal quality of environment among buildings.

Bustos Romero (1988) considers factors such as localization, ventilation, wind speed as well as orientation and insulation. He also highlights as intervening elements morphology, open, closed, dispersed, compact form, density, separation among buildings, building heights, barriers of wind conduction, solar radiation exposure, nature of superficial elements and climate balance. In terms of the building site, orientation, dimensions, form, occupation, alignment, closures and superficial materials as well as vegetation, ventilation, shadows, presence of water, humidity and lightning are underlined. In the mentioned studies, there are coincidences of some constants such as intervening elements, which are grouped in three categories (Table 1). The categories and associate variables constitute the key elements-components that characterize the comprehensiveness of micro space and conform multiple dimensions considered in the construction of micro climatic scenarios of the micro space (Gomez, 2010).

<i>Climatic mean</i>	<i>Urban morphology</i>	<i>building</i>
<ul style="list-style-type: none"> <li>• <i>Solar radiation</i></li> <li>• <i>shadows</i></li> <li>• <i>Orientation</i></li> <li>• <i>Winds</i></li> <li>• <i>lightning</i></li> <li>• <i>Vegetation</i></li> </ul>	<i>Structure and urban morphology</i> <ul style="list-style-type: none"> <li>• <i>Urban net</i></li> <li>• <i>Orientation</i></li> <li>• <i>Occupation density</i></li> <li>• <i>Building heights</i></li> <li>• <i>Localization of building site</i></li> <li>• <i>Size, geometry and land surface</i></li> </ul>	<ul style="list-style-type: none"> <li>• <i>Enveloping characteristics</i></li> <li>• <i>Building elements</i></li> </ul> <i>Structural characteristics</i> <ul style="list-style-type: none"> <li>• <i>Materials /Finishes</i></li> <li>• <i>Color</i></li> <li>• <i>Pavements and walls</i></li> </ul>

*Table 1. Categories of constant intervening variables in outer space*

In the proposed systemic and modeled statement, it was necessary to combine the relevant key elements considering the three components-elements identified as: *Environment*, *Base and Limit surface*; these correspond to space, physical enveloping and the micro climate. The *Environment* involves climate conditions of such micro space; the *Base* corresponds to space where micro space settles; the *Limit surface* refers to the limit or the frame of space that surround us (Imagen 1). The elements that comprise this body represent the synthesis and fit in the parts that interact and form the scenarios to be proposed.



*Imagen 1. Components-elements of micro space*

The first component comprises the access to environmental elements such as: sun, temperature, humidity, sun radiation, shades, winds, conduction and canalization of winds and vegetation. The second component includes the morphotypological factors of space located in the base plan such as: occupation, building typology, building heights, localization and distribution in the lot, size, geometry and surface of the lot, pavements, walls and covers. While the third component deals with the elements of the building and the quality of the enveloping: surface area, openings, materials, finishes and color. These components act systematically in the micro space and must be treated simultaneously and interrelated linking the morphotypological and building components with the micro climatic environment.

In the study on sustainability, Kees (2006) proposes using the term “situation” to describe the condition of micro space in its whole complexity. It refers to the capacity to keep elements together which are often heterogeneous by common situations, as well as giving them a common meaning. The term situation (taken from strategic planning) is useful, because it is about recognizing a moment within the continuous process of spatial, time and social transformation in which space is involved and it corresponds to a comprehensive approach with a simultaneous strategic vision instead of a linear plan of following phases. Simultaneity and approach density revolve around a net capable of capturing the complexity of different elements; it is a method that allow facing the complexity, recognition, vision and comprehensive solution of the urban micro space.

### **1. Systemic strategy**

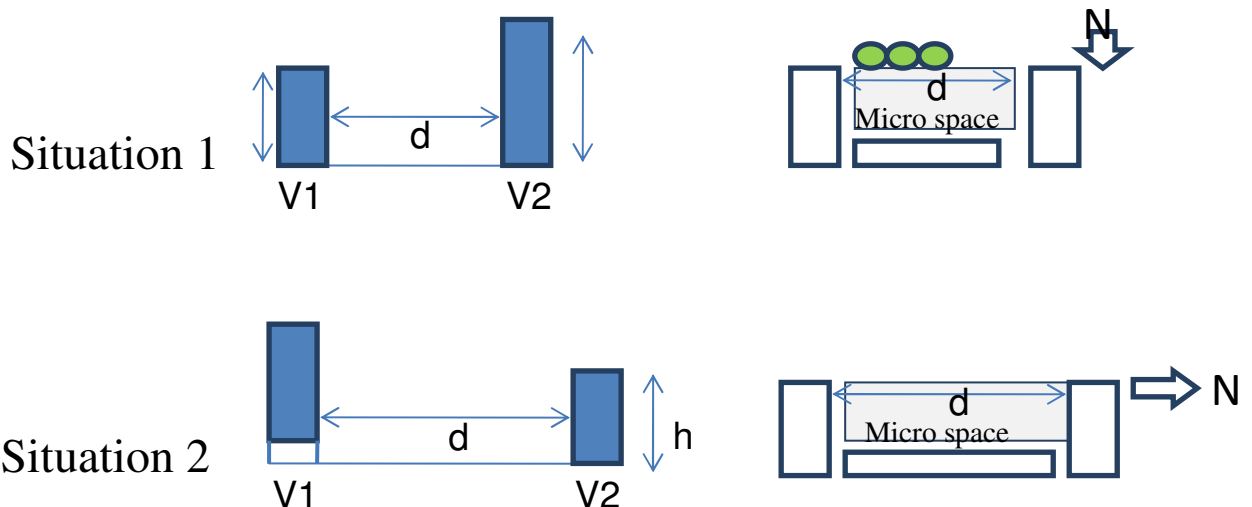
From the relationship system suggested, it is proposed the micro climatic scenario modeling as well as the main referents supported in the review that combine parameters and highlighted intervening variables abroad. The heuristic approach, iterative among the key variables that define the environmental behavior in order to formulate micro climatic strategies in current urban developments were privileged (Gómez, 2010). This strategy

intends to meet comprehensive solutions from the sustainable design principles. In order to apply it, it is necessary to previously take a comprehensive evaluation of the micro space to determine the place of the elements or conditionings of the polyvalent comprehensive conception; that is to say, the space in its three dimensions. This analysis contributes to the definition of designing parameters incorporated to the materialization process of urban form.

The strategy proposed consists of the three (3) dimensions of the study: the Environment, the *Spatial Coordinate* deals with the environmental conditions; the Base and Limit Surface, the *Urban-Building Coordinate* includes the morphotypological characteristics and building and material characteristics; *Time Coordinate*, the use and schedule. These three coordinates form the *System of Relationship or Strategy* to build micro climatic scenarios in the micro urban scale. The interconnection of components-elements and the comparison-synthesis of the system of relationships allow establishing and characterizing the constant within the micro space configuration. The main idea is to create a Strategic Guide for urban-environmental planning and designing whereby the micro space has to have a definite, designed and built shape with as much intention as architecture. It is about the architectural conception of public space.

**Modeling:** modeling comprehends spatial and environmental elements constant in public space and comprises the following phases:

- A. Selection of study areas according to proposed criteria.
- B. Records of different “situations” of relationship among the components-elements: Environment, Base and Limit Surface according to the morph-urban condition (distances, orientation, surfaces), volumetric configuration (heights, dimensions, elements) and pavements (types and properties) (Imagen 2)





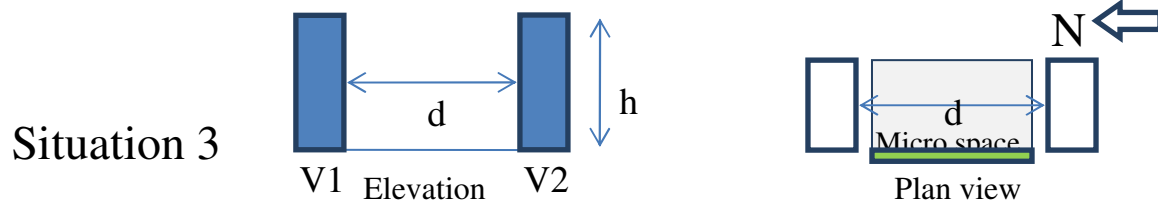


Imagen 2. Record of different situations of the components-elements

C. Determination of scenarios for each “registered situation” through the interaction-contrast of components-elements for each spatial established unit. The system of relationships rules over the interaction of variables, which constantly intervene in the micro space and define the three proposed coordinates: spatial, time and urban-environmental. The purpose is to determine the effects and strategies of thermal control.

**C.1 Environment and Base Relationship.** Variables of components-elements interconnect to achieve strategies that guarantee exterior comfort. In order to obtain *Solar Block*, orientation, localization of elements, density and distance among buildings are interrelated, which contributes to guarantee permanent shadow in the micro space (Table 2). The greater the density is, the greater is the possibility of shadow according to the cast shadow. Likewise, the disposition and discrepancy of buildings promote the production of cast shadows towards the surrounding environment. The correlation between orientation and dimensions of the lot allow controlling the angle of exterior solar obstruction, and the curve of solar obstruction admits the orientation of space towards determined situations.

Environment and Base Relationship						
Environment	BASE					
	Dimension of the lot	Localization of elements	Density	Distance among buildings	Type of pavement Color	Pavement properties
Orientation	Solar block				Surface Control	
Radiation	Solar radiation control					
Ventilation	Movement of the air					
Vegetation	Solar radiation control				Solar radiation control	

Table 2. Environment and Base Control

Orientation, pavements, type, color and surface properties are linked in order to control *Solar Radiation*. This interrelationship contributes to define the typology of exterior surfaces according to reflection coefficients. On the other hand, wind, orientation, distribution of

usages, density and localization of elements are linked in order to control the movement of air effects of rotation and flow; so, this contributes to air movement and adequate flow of ventilation. While for vegetation, dimension of lot, disposition ( $\text{m}^2$  per person) and green distribution are interrelated. The presence of green intervenes in the control of solar radiation and as a vegetable protector.

**C.2 Environment and Limit Surface relationship.** In order to control radiation, orientation, location of façades and volume dimensions of variables according to the angle of solar obstruction are linked (Table 3). This help to control sun exposure and to reduce sun hours as well as to guarantee self-protection and permanent shade of the environment. Orientation, height and separation of buildings must be considered for each orientation. Leveling is not permitted. For *passive conditioning*, the following variables ventilation, typology of the building and volume dimensions are linked. The relationship among orientation, block typology, dimensions of openings, surface finishes and protective elements conditions ventilation crossing and acts as a barrier that can generate changes of direction and wind speed as well. In order to control vegetation, the green and the built enveloping as a protection measure and as vegetable framer and protection cover.

Environment and Limit Surface relationship					
ENVIRONMENT	Limit Surface				
	Heights	Volume dimensions	Building typology	Enveloping surface	Distance among buildings
Orientation	Solar block				Solar block
Radiation				Solar radiation control	
Ventilation	Open block			Passive Conditioning	
Vegetation		Solar radiation control			

Table 3. Environment and Limit surface

**C3. Environment – timing period relationship.** The components Base and Limit Surface per spatial unit with temperature, solar radiation and ventilation during representative periods of time according to climate and micro space orientation are interconnected (Table 4). Thermal variables that act in combination are compared to Comfort ranges of local Psychometrical Diagram, which establishes the levels of comfort guaranteed. The type and distribution of vegetation is another variable to control.

Environment – timing period relationship			
ENTORNO	PERIOD - TIME		
	Morning period	Meridian period	Evening period
Orientation	Physical and urban characteristics	Physical and urban characteristics	Physical and urban characteristics
Temperatura			
Radiation			
Ventilation			
Vegetation			

Table 4. Environment – timing period Control

From these models, the construction of computer simulation scenarios are is feasible in order to evaluate the variable behavior according to every single situation. Analysis and comparing components could allow establishing the adequate thermal requirements within the urban micro space.

## REFERENCES

- (1) Bustos, R, M. (1988). *Principios Bioclimáticos para o Desenho Urbano*. Tesis de Doctorado: Universidad de Sao Paulo. Brasil.
- (2) Unión Europea (1996). Informe de Ciudades Sostenibles. Comisión Europea. Dirección General XI Medio Ambiente, Seguridad Nuclear y Protección Civil. [Documento en línea]. Disponible En: <http://ec.europa.eu/environment/urban/pdf/rport-es>.
- (3) Gehl J (2006). *La Humanización del Espacio Urbano*. Estudios Universitarios de Arquitectura. España.
- (4) Nikolopoulou , M., y Steemers, K. (2003). *Thermal comfort and psychological adaptation as a guide for designing urban spaces*. En Energy and Buildings, 35(1), pp. 95 - 101.
- (5) Kees C (2006). “Sostenibilidad en el diseño urbano” en Eco-Barrios en Europa. Nuevos entornos residenciales. Madrid: 53-70
- (6) Olgyay (1968). Design with Climate. Princeton University. Princeton
- (7) Givoni B (1989). “Urban Design in different Climate”. Report WMO/TD-No.346, World Meteorological Organization. Geneve.
- (8) Gómez N (2010). *Microclimatic study of the space between buildings. Case: Urban housing developments, Maracaibo (Venezuela)*". En Revista Técnica. Facultad de Ingeniería, Universidad del Zulia-LUZ.

## The effect of land cover and land use on urban heat island in Taiwan

Feng-Chi Liao<sup>1</sup> ; Ming-Jen Cheng<sup>2</sup> ; Reuy-Lung Hwang<sup>3</sup> ; Wen-Shan Yang<sup>4</sup>

<sup>1</sup>Program in Civil and Hydraulic Engineering, Feng Chia University, Taichung, Taiwan

<sup>2</sup>Department of Architecture, Feng Chia University, Taichung, Taiwan

<sup>3</sup>Department of Architecture, National United University, Miaoli, Taiwan

<sup>4</sup>Program in Civil and Hydraulic Engineering, Feng Chia University, Taichung, Taiwan

### Abstract

*The global warming get worse as problems on highly land developed, other artificial heat influences, and especially it causes that urban heat island effect with highly intensive population and makes the living environment worse. Finally, we mainly investigate the influence of land use on urban heat island (UHI) and study impact factors of urban microclimate in Taiwan. In the study, we established 20 different measuring points in Taichung, Taiwan (120°40'E, 24°08'N) with fixed-point monitoring. We analyzed the correlation of land use pattern factors and variations in UHI strength by buffering analysis, ANOVA, multiple regression analysis, and then we established air temperature regression model. Finally, we found that it had the highest correlation between the building area and UHI strength, and the results shows that the average UHI strength during the period of experiment is about 0.96 °C and the maximum vaule is 1.49 °C.*

**Keywords:** *land use, urban heat island (UHI), fixed-point monitoring, multiple regression analysis*

### 1. Introduction

After the Industrial Revolution, urbanization is an apparent appearance in every country, and the environment has become different from the past decades. All the research indicate that the microclimate in urban has become more and more heater. The urban heat island effect has happened in some city in Europe, such as London. Other Cities in different country also have the same problem. For example, the temperature in Tokyo city has risen up since 1920, and the upward trend exceeds the average of the Tokyo County. Therefore, Sciences had attached importance to the urban microclimate since the 20th century. Surveyed all the reverences in the world, the factor which affect the urban microclimate included the sky view factor (SVF), surface albedo, ratio of green cover, building height/street width (H/W), and land use/land cover (LCLU). The LCLU composition includes the buildings, streets, plants, and water, which can rise or decrease the temperature. It might be the improvement factors of the urban microclimate.

Because of the references on urban climate didn't take the types of LCLU as the main factor, therefore the purpose of this study will include constructing the database of urban microclimate in midland of Taiwan, surveying the correlation between the Land Use and the

urban microclimate, analyzing how the Land Use effects the urban heat island effect in Taiwan.

2. Materials and Methods

2.1. Definition of land cover and land use

As Fig.1 shows, the LCLU patterns around the survey point could be classed into two categories, the hard or the soft pavement. And it also could be classed into five factors: (1)the building area(Ba), which included all the structures; (2)the paved area(Pa), which included the asphalt road, the sidewalk, and the impermeable pavement; (3)the free area(Fa), which included the back yard, the grassun-shade by trees, and the unpaved soil surface; (4)the green area(Ga), which shaded by trees; (5)the water area(Wa), which included the rivers, the lakes, and the ponds.

2.2. Field measurement



Fig.1 Description of LCLU patterns.

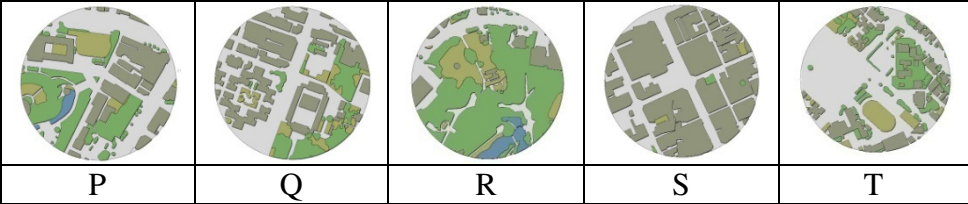


Fig.2 Location of Taichung City and 20 measuring spots.

Table 1 Locations description on LCLU patterns. (radius : 150 meters )

A	B	C	D	E
F	G	H	I	J
K	L	M	N	O





In this study, the fieldwork is surveying in fixed-point monitoring. The measurement spots had to be consistent in the impact of traffic, street orientation, street and building aspect ratio, and green trees. In order to obtain the variation of the temperature and enhance its credibility, we chose 20 measurement spots, which were distributed in the axis of downtown to the outskirts of Taichung City and around the dense population and activities areas, as Fig. 2 shows. We carry out the fieldwork and analyze the aerial photographs of the measurement spots to diagram the LCLU patterns. And then we differentiate and quantify the composition of LCLU patterns around the measurement spots, as Table 1 shows.

Then, we monitored the temperature and humidity in July to September 2008 and 2009 with the iLog sensor. We set a well-ventilated white cover on top of the sensor, in order to avoid direct exposure to the sun and rain. And we also used wooden structure to set the sensor on a light pole at 3 meters high and at least 1.5 meters far away the buildings to avoid the artificial damage, and reduce the effect of radiant heat from the buildings and grounds. In addition, sensors were all located on the north side of streets as the different of sunshine duration.

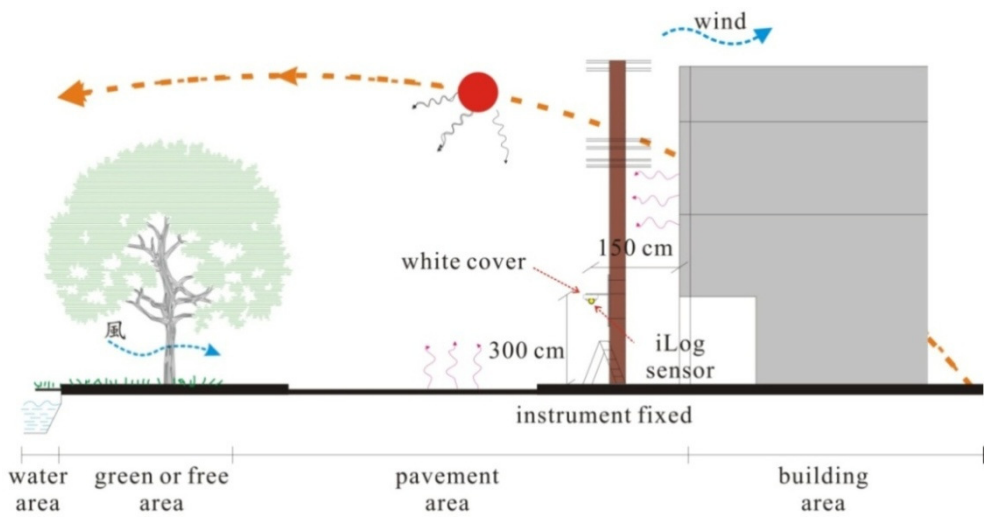


Fig.3 Description of setting i-Log sensor.

3. Results and Discussion

3.1. The contrast between local temperature

After surveying, we had 68 valid data by excluding cloudy and rainy days, and we took the climatic data from Taichung meteorological station to be the reference. Based on the related research and the buffering analyzing with a 50m/100m/150m/200m/300m radius of the measurement locations, it indicates that the parameters of the microclimate is most related to the Land Use patterns within a 150m radius, therefore, we take i as the criterion for this study. The Fig. 4 shows that all the data of each measuring spots and the Land Use patterns.

### (1) The daily average temperatures

The different LCLU patterns and the artificial heats primarily affected the daily average temperature of each measurement spot. We found that the daily average temperature of spot K is  $31.47^{\circ}\text{C}$ , which is the highest among all. The daily average temperature of spot F, N, and Q were over  $31.3^{\circ}\text{C}$ , and the ratio of hard pavement in these three spots was more than 80%. Furthermore, the daily average temperature of spot J is  $29.94^{\circ}\text{C}$ , which is the lowest, and the ratio of soft pavement in J spot is 53%.

Besides, the data indicated that the maximum temperature of each day is affected not only by the different LCLU patterns, but also by the size of surface heating area around the measuring location and the artificial heats.

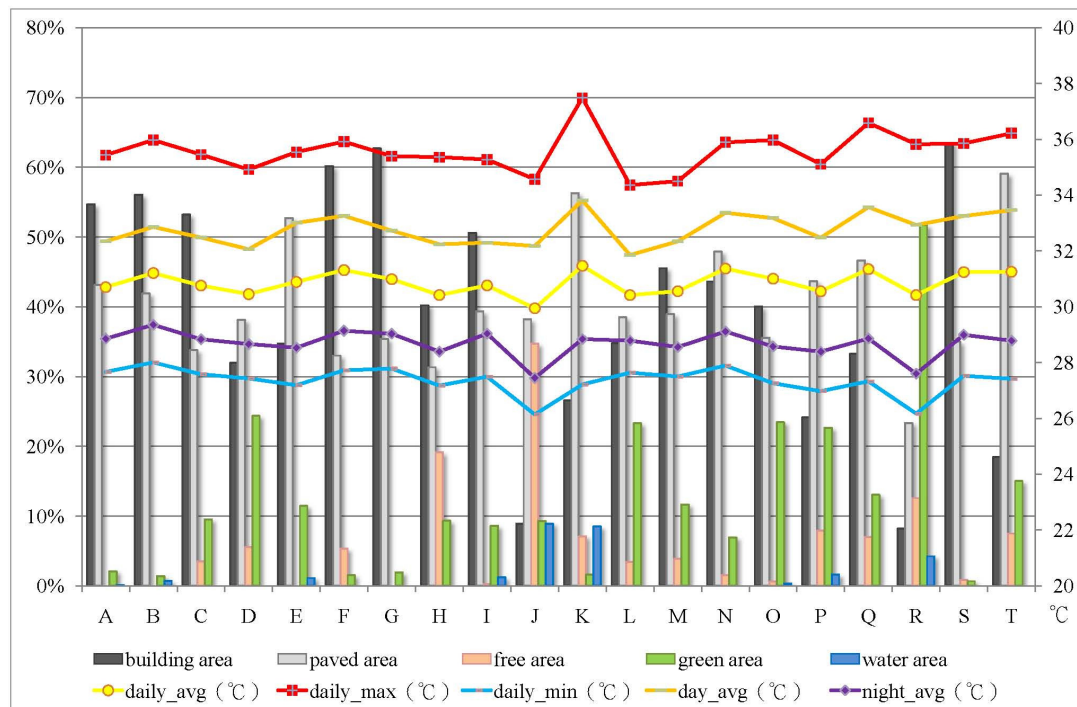


Fig.4 Collection of the climatic data and LCLU patterns for each spot.

### (2) The average daytime temperatures

In daytime, we found that the building is an endothermic factor in daytime, but its shadow will reduce the temperature around. The more Pa will accelerate the absorption of heat in the surface, and then increase the temperature. The Fa could heat up the air faster, even if it wasn't an endothermic factor. On the contrary, the Ga can reduce the temperature of measuring spots, and the Wa could cooldown around.

### (3) The average nighttime temperatures

The temperature of each measuring location had the same variation phenomenon at nighttime. The difference in the average of nighttime temperature of each measuring spot is  $1.9^{\circ}\text{C}$ . On the contrary, the building and the artificial pavement would radiate the heat slowly, which

they absorb in daytime. On the contrary, the free area, green area, and water could cool down the temperature of measuring location.

#### (4) Temperature differences

To explore the difference of the temperature between downtown and outskirts, we analyzed the data of spot B and J first, and we discovered that the difference of the daily average temperature was  $1.54^{\circ}\text{C}$ , and the maximum temperature difference was  $2.23^{\circ}\text{C}$  occurred at 20:00. As Fig. 5 shows, the difference of the temperature had the same variation phenomenon at night. The average difference between spot B and J was  $1.96^{\circ}\text{C}$ .

Secondly, exploring the overall temperature difference between the whole city and the outskirts, we analyzed the data of location J and the highest temperature spot of all, then we measured the UHI strength by the average of temperature difference between spot J and others. The results indicated that the temperature differences of spot B almost consistent with spot J. The temperature difference was lower as  $1.18^{\circ}\text{C}$  in the morning, but it significantly increased in the afternoon, especially at the measurement spot with larger ratio of the Pa and Ba. And the maximum temperature difference was  $3.85^{\circ}\text{C}$  occurred at 19:00. In brief, all the maximum temperature of every measurement spots were higher than spot J, and the average temperature differences was  $2.1^{\circ}\text{C}$ . The maximum UHI was  $1.49^{\circ}\text{C}$  occurred at 19:00.

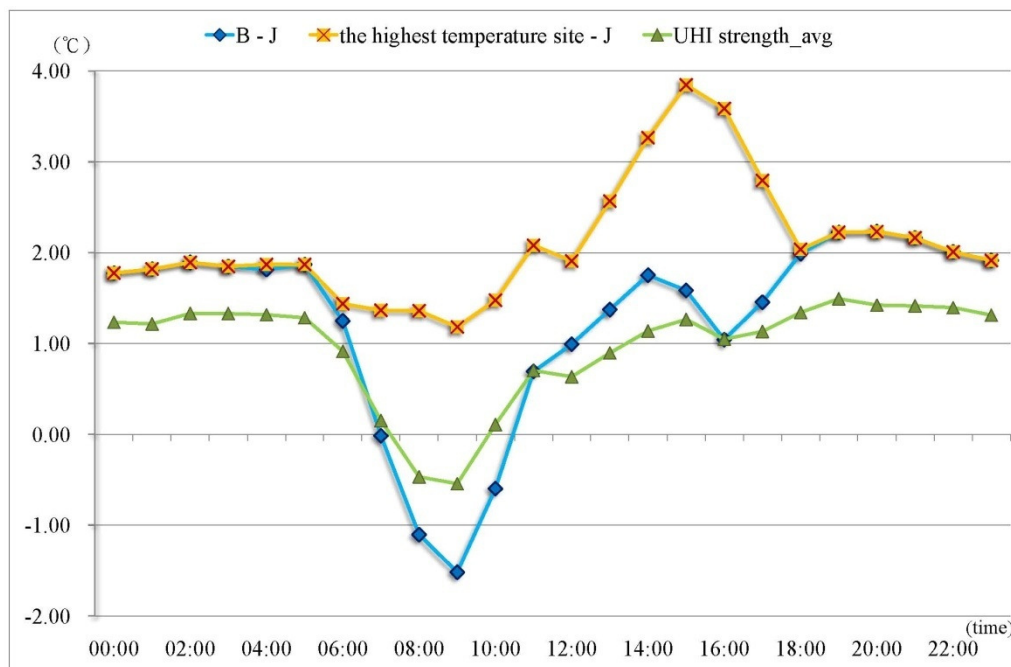


Fig.5 The daily mean temperature difference

### 3.2. Quantitative analysis

#### (1) One way ANOVA

In this study, we analyzed the relationship between the climate data and the LCLU patterns by ANOVA for regression. Table 2 shows that the daily average temperature was obvious related

to the Pa, Fa, and Ga. The area of Pa was obvious related to the average daytime temperature, and the average nighttime temperature was obvious related to the Ba, Fa, Ga, and Wa. by differential thermal analysis , we found that the daily average temperature difference was obvious related to the Pa and Ga. The Pa was obvious related to the average daytime temperature difference, and the average nighttime temperature difference was obvious related to the Ba, Fa, and Ga.

## (2) Multiple Regression

With stepwise regression, we confirmed the significant factor by buffering analysis and one-way analysis of variance. And then we analyzed the LCLU patterns in accordance with the average temperature of the whole day, the daytime, and the nighttime by multiple regression analysis. And Table 3 shows the results.

Table 2 The P value of the significance for LCLU factors to air temperature ( $\alpha = .05$ )

Factors	Ta <sub>avg</sub>			$\Delta$ Ta <sub>avg</sub>			UHI strength ( $\Delta$ Ta at 19 : 00)
	daily	day	night	daily	day	night	
Ba	.070	.990	.000	.092	.174	.000	.004
Pa	.033	.048	.194	.023	.034	.068	.246
Fa	.007	.098	.000	.069	.964	.004	.083
Ga	.043	.123	.004	.011	.133	.000	.000
Wa	.325	.179	.007	.511	.053	.172	.776

Table 3 The multiple regression model for air temperature and LCLU

Parameter	Formula	R <sup>2</sup>
Daily_Ta <sub>avg</sub>	$32.21 - 1.64 \times Ba - 0.32 \times Pa - 4.39 \times Fa - 2.56 \times Ga$	0.54
Day_Ta <sub>avg</sub>	$31.96 + 2.2 \times Pa - 2.37 \times Fa - 0.1 \times Ga + 6.14 \times Wa$	0.27
Night_Ta <sub>avg</sub>	$29.35 - 0.34 \times Ba - 3.47 \times Fa - 2.18 \times Ga - 3.78 \times Wa$	0.86
Daily_ $\Delta$ Ta <sub>avg</sub>	$0.96 - 3.55 \times Ba - 2.35 \times Pa - 4.52 \times Fa - 4.87 \times Ga$	0.48
Day_ $\Delta$ Ta <sub>avg</sub>	$1.49 - 0.34 \times Ba + 1.77 \times Pa - 0.99 \times Ga + 9.74 \times Wa$	0.30
Night_ $\Delta$ Ta <sub>avg</sub>	$0.44 + 2.97 \times Ba + 3.26 \times Pa + 0.69 \times Fa + 0.98 \times Ga$	0.81
UHI strength <sub>avg(19:00)</sub>	$(\Sigma 0.36 + 0.86 \times Ba + 0.83 \times Pa - 2.84 \times Fa - 1.31 \times Ga) / n$	0.69

## 4. Conclusions

In this study, we analyzed the temperature by fixed-point field measurement and regression analysis. We explored that the hard pavement, such as the Ba, and Pa, would absorb heat at daytime and radiate the absorbed heat at nighttime. Resulting in the spot with more ratio of Pa cooled down slower than with more ratio of soft pavement, such as Fa, Ga, and Wa. More Ga and Fa area would cool down the urban microclimate more, especially at night. On the contrary, more Ba and Pa area would heat up the urban microclimate, especially at daytime.

By analyzing the temperature difference of each spot, the LCLU pattern wasn't related to the temperature difference of daytime. We confirmed the Pa and Ga were the main impact factor, but the shadow of buildings could due to the downtown temperature higher than the outskirts in the morning. The Ba, the Fa, and Ga obvious related to the average temperature difference of the nighttime. During the measurement period, the average UHI is 0.96°C. The maximum



UHI was  $0.96^{\circ}\text{C}$  occurred at 19:00 because of the heat absorption and radiation of the Pa, and the outskirts cooled down faster than downtown.

Finally, we established the correlation model of the LCLU patterns and the temperature by multiple regressions. And we explored that the LCLU pattern obvious related to the average temperature of the nighttime and the average nighttime temperature difference of each measuring spot. The maximum temperature difference of whole day was  $4^{\circ}\text{C}$  because of the different LCLU patterns. The difference of maximum average temperature was  $2.52^{\circ}\text{C}$ , and the difference of maximum UHI was  $3.7^{\circ}\text{C}$ . In brief, the LCLU pattern was an important impact factor to the urban microclimate.

## 5. References

1. Haider Taha. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and Buildings*, 25: 99-103, doi: 10.1016/S0378-7788(96)00999-1.
2. Hadas Saaroni. Eyal Ben-Dor. Arie Bitan. Oded Potchter. (2000). Spatial distribution and microscale characteristics of the urban heat island in Tel-Aviv, Israel. *Landscape and Urban Planning*, 48: 1-18, doi: 10.1016/S0169-2046(99)00075-4.
3. H, Akbari. M, Pomerantz. H, Taha. (2001). Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas. *Solar Energy*, 70(3): 295-310, doi: 10.1016/S0038-092X(00)00089-X.
4. Z, Bottya'n. J, Unger. (2003). A multiple linear statistical model for estimating the mean maximum urban heat island. *Theoretical and Applied Climatology*, 75: 233-243, doi: 10.1007/s00704-003-0735-7.
5. Janet Nichol. (2005). Man Sing Wong, Modeling urban environmental quality in a tropical city. *Landscape and Urban Planning*, 73: 49-58, doi: 10.1016/j.landurbplan.2004.08.004.
6. Alexander Velazquez-Lozada. Jorge E. Gonzalez. Amos Winter. (2006). Urban heat island effect analysis for San Juan, Puerto Rico. *Atmospheric and Environment*, 40: 1731-1741, doi: 10.1016/j.atmosenv.2005.09.074.
7. N,H, Wong. Steve Kardinal Jusuf. Aung Aung La Win. Htun Kyaw Thu. To Syatia Negara. Wu Xuchao. (2007). Environmental study of the impact of greenery in an institutional campus in the tropics. *Building and Environment*, 42: 2949-2970, doi: 10.1016/j.buildenv.2006.06.004.
8. Chuan-Yao Lin. Fei Chen. J,-C, Huang. W,-C, Chen. Y,-A, Liou. W,-N, Chen. Shaw-C, Liu. (2008). Urban heat island effect and its impact on boundary layer development and land-sea circulation over northern Taiwan. *Atmospheric Environment*, 42: 5635-5649, doi: 10.1016/j.atmosenv.2008.03.015.





9. Hwang, R.L.. Lin, T.P.. Matzarakis, A.. (2011). Seasonal effect of urban street shading on long-term outdoor thermal comfort. *Building and Environment*, 46(4): 863-870, doi: 10.1016/j.buildenv.2010.10.017.
10. Sun, C.Y.. Lee, K.P.. Lin, T.P.. Lee, S.H.. (2012). Vegetation as a material of roof and city to cool down the temperature. *Advanced Materials Research*, 461: 552-556, doi: 10.4028/www.scientific.net/AMR.461.552.